Experimental and numerical investigations on the behaviour of concrete filled steel tube and channel shear connectors in push-out tests

K M Alnebhan¹², M A Shallal¹³

Civil Eng. Dep., College of Engineering, University of Al-Qadisiyah, Iraq.

²kmj72j@gmail.com

³mohanad.shallal@qu.edu.iq

Abstract. The use of shear connectors in the steel-concrete structural system is widely used to connect the steel and concrete parts of the system. The push-out test is the standard test used to detect the load capacity of different types of shear connectors. In this study, the push-out test was performed on concrete filled steel tube connected using channel shear connectors. The effect of concrete block strength and the exist of concrete core were investigated. Using concrete filled steel tube with increasing the compressive strength of the slab gain higher loading capacity and less slipping than hollow steel tube and low compressive strength of the concrete block. The experimental results were validated using ABAQUS finite element model. A numerical parametric study was carried out to show the effect of the value of concrete block compressive strength, length of the channel connectors, the strength of CFST and the yield stress of these connectors. It turns out that when increases either the length of shear connector or the concrete block strength or the yield stress of shear connector, the ultimate load increases, while the strength of CFST has no effect on ultimate load.

Keywords: Concrete filled steel tube; Channel shear connectors; push-out test; ABAQUS model, composite concrete-steel, concrete compression strength.

1. Introduction

The combination of two materials to produce composite structure owning the integration of the properties of these two materials is a promising method to overcome some problems in the construction industry. For several decades, the use of steel in combination with concrete has been more successful and widely applied structural system. In order to transfer the load across the concrete and steel interface, especially longitudinal shear force, shear connectors (Figure 1) were utilized to stand for this position [9]. This made the use of a suitable connecting system to merge them to get the ultimate benefit of their properties together is a very important issue.

To ensure the composite system is working properly as it is designed for, the push-out test was presented around the year 1920 [14] and was commonly used, since then by many researchers, as a standard test to study the load–slip behaviour of numerous types of shear connectors as well as the shear capacity of these connectors [12, 13, 16-18].

The alternative method for this test is to simulate numerically the push-out behaviour of these shear connectors using the finite element method [5, 9, 11, 17].

Welded headed studs were commonly used as a shear connector for composite steel–concrete structures. Significant researches were carried out to investigate the load-slip behaviour in the push-out test [3, 13, 16].
The conclusion of these researches was that using such connector improve significantly the shear resistance of the composite concrete-steel structure. These results were validated numerically, by several researchers [5, 9, 11, 13] using different finite element software packages.

The use of high strength bolts shear connector was studied experimentally, conducting a push-out test, and numerically by Marko et. al. [13]. The results were compared to that of experimental studies results conducted by other researches in which headed studs were used. They found that bolted shear connectors are higher static load shear resistance by 95% than that of conventional welded headed studs.

The use of rip shear connectors was also suggested by Oguejiofor and Hosain [12]. The influence of the hole’s number and spacing of the rips used, the concrete compressive strength and the transverse reinforcement were investigated. The results showed that the shear capacity of such type of connectors increases with increasing the number of holes when the spacing is more than 2.25 times the hole’s diameter. Increasing the transverse reinforcement and compressive strength results in a similar trend in increasing the shear capacity of rib connectors.

The push-out test results of I-shape shear connectors were presented experimentally and numerically by Titoum et. al. [12]. The slip capacity was found to be greater than 6 mm and the uplift values were small. For this reason, it was concluded that this type of connectors was considered, according to Eurocode 4, as a ductile connector.

Concrete filled tube is a promising composite material which has been used in several structural applications. It is the concrete cores embedded in a steel tube. In this system, the concrete and steel are perfectly compatible and integrated with each other. The shear connectors play a major role in resisting the shear flow and preventing the uplifting resulting from loading the composite structure. Using channel shear connectors in this type of material is rarely investigated [6, 15].

The push-out test, for concrete-filled steel tube connected to the concrete slab using channel shear connectors, was performed in this study. The effect of using hollow steel tube and that filled with concrete on the test result was investigated. The influence of using different compressive strength values for the concrete slab was also studied.

The experimental results were validated using finite element software package ABAQUS. A parametric study was also carried out to provide a clear understanding of the effect of variation in concrete slab compressive strength, length of the channel connectors and its yield stress.

![Types of shear connectors](image1)

Figure 1 Types of shear connectors
2. Experimental work

In the composite concrete steel, the U50x25 shear connector channel was adopted in this study with length 80 mm.

In order to investigate the load-slip relation and determine the ultimate capacity of these connectors, three push-out specimens as shown in Figure 2 were constructed D60C50, D30C50 and D60C0 to find the ultimate capacity of single shear connectors channel. The concrete strength of concrete filled steel tube were labelled as (C), the reinforcement concrete block was labelled as (D). Two specimens were filled by self-compacting concrete with strength of (50 MPa) (labelled as C50) and the third specimen was hollow steel tube (labelled as C0).

Each specimen consists of steel tube which has dimensions of (100×100×3.8) mm with a short length of (500 mm). This tube was connected to two reinforcement concrete blocks with dimensions of (500×400) mm, having the thickness of (75mm) and each block reinforced with two layers of reinforcement steel bar 8 mm in diameter.

In specimens, a single shear connector channel was welded at two sides of steel tube. The self-compacting concrete was cast vertically into the steel tube, then after 10 days the concrete block was poured into the molds (shown in Figure 3) and cured for 28 days.

A Universal Testing Machine was utilized for the push-out tests. The slip at the interface of the concrete blocks and the steel tube was recorded as a result of this test by using two LVDT as shown in Figure 4.

3. Material properties

3.1 Concrete

As stated earlier, self-compacting concrete (SCC) was adopted in this research to fill the steel tube. Its production needs special materials with specified production method to meet the requirements of the European Federation of Specialist Construction and Concrete (EFNARC) specifications [2]. SCC contains mineral and chemical admixtures in addition to the ordinary materials (cement, sand, gravel, and water).

Table 1 shows the mix proportions of M30, M50 and M60 were adopted for SCC mixes to fill the steel tubes as well as for casting the slabs and the results of cubic test C and D.

| Mix | Cement (kg/m³) | F.A. (kg/m³) | C.A. (kg/m³) | L.P. (kg/m³) | S.P (kg/m³) | Water/Cement (kg/m³) | C (MPa) | D (MPa) |
|-----|----------------|--------------|--------------|--------------|-------------|----------------------|---------|--------|
| M30 | 300            | 670          | 730          | 110          | (1%)        | (0.7)210             | 31.86   |        |
| M50 | 450            | 670          | 730          | 90           | (1.5%)      | (0.42)189            | 48.41   | 31.86  |
| M60 | 450            | 670          | 730          | 90           | (1.75%)     | (0.36)162            | 48.41   | 61.47  |

F.A. is represent fine aggregate.
C.A. is representing coarse aggregate.
L.P. is representing limestone powder.
S.P is representing superplasticizer.
C is representing the concrete filled steel tube strength.
D is representing the concrete block strength.

3.2 Steel

The tensile strength test for three specimens of each steel section’s type were conducted. The outputs and the conducted method of the tensile test for different steel types show in Table 2, that were used in the specimens, is agreed with ASTM A615-04 [10].
Table 2 Steel properties

| Section             | Yield Stress (fy) (MPa) | Ultimate Stress (fu) (MPa) |
|---------------------|-------------------------|---------------------------|
| Tube (100x100x3.8)  | 328.2                   | 372                       |
| Channel (U50x25)    | 344.4                   | 487                       |
| Bar (Φ 8 mm)        | 401.5                   | 598.8                     |

Figure 2 Push-out test specimen

Figure 3 Casting the concrete for push-out test
4. Experimental results

The push-out tests’ results of shear connectors channel are recorded in Table 3. Figure 5, is showing the load slip relationship for three specimens. When comparing between the results of the specimens it was observed that the strength of concrete block had clear effect on the results where the specimen D60C50 was failed in higher ultimate load by 66.6% and less slipping by 7.55% than the specimen D30C50. We can see that the ultimate load depends on the strength of the concrete block where the ultimate load decreases when reduces the strength of concrete.

The specimen D60C0 with hollow tube was less than D60C50 in the ultimate load by 11.21% and slipping by 36.54%, where D60C0 was failed by local buckling in the steel tube as shown in Figure 6 c. Figure 6 (a, b and c) shows the failure mode of all specimens. The failure mode of D60C50 was the obvious cracks in the concrete, while the failure mode of D30C50 was crashing the concrete around the shear connector and its separation from the steel tube. Obviously, the reason failure is different from the D60C50is that the concrete strength is less and causes the concrete to fail by less ultimate load. The failure mode of D60C0 was by local buckling in the hollow steel tube, we can conclude that the concrete infill prevents steel tube buckling.

Table 3 shows that the slight difference of the stiffness between D60C50 and D60C0, the reason is that the strength of the concrete block is equal. While the stiffness of D30C50 less than the other specimens because of strength of concrete block was less.

Figure 4 The push-out test
| Specimen | Ultimate load (kN) | Total slip (mm) | Stiffness (kN/mm) |
|----------|-------------------|-----------------|------------------|
| D60C50   | 439.831           | 3.872           | 633.16           |
| D30C50   | 264.026           | 4.188           | 386.48           |
| D60C0    | 390.510           | 2.457           | 549.27           |

**Figure 5** Load-slip relationship of the specimens

**Table 3** The results of push-out test
5. Finite element model

The software package ABAQUS[1] was used to carry out the finite element analysis to simulate the behaviour of shear connectors channel with concrete filled steel tube in the push-out test. The FE model was validated with the test results.

A bilinear model with Von Mises yield criterion were utilized for modelling the behaviour of steel (reinforcement bars, tube and channels) and Concrete Damage Plasticity Model were utilized for modelling the behaviour concrete.

Many elements were used in representation of adopted specimens and geometrical properties. The used elements in finite element model can be summarized by:

1. C3D8R: 8-node linear brick, reduced integration, hourglass control used to represent the concrete block, steel tube, shear connectors channel, covers of the steel tube and the concrete infill the steel tube.
2. T3D2: 2-node linear 3-D truss which were used to represent the rebar of concrete blocks.
3. R3D4: 4-node 3 D rigid element which were used to represent the base block of load.

The friction coefficient of the inner steel tube-concrete interface was taken (0.3) [4], the friction coefficient of steel tube-concrete block interface was taken 0.1 and the friction coefficient of steel channel-concrete block interface was taken 0.2 [5].

Five different mesh sizes were used for analysis of specimen for purpose of finding convergence between the curves to choose the appropriate mesh for the model analysis. The Figure 7 (a, b, c, d and e) shows the mesh sizes (0.01-0.05) and the Figure 8 show the results of load-slip analysis for the specimen D60C50 by using different mesh sizes (0.01,0.02,0.03,0.04 and 0.05).

When observing the Figure 8, we note that the convergence of the curves was done by using mesh size (0.01) and (0.02), so the mesh size (0.01) was used in the model analysis.
The compression uniaxial behaviour of the concrete material was specified using the model developed by Hognestad [7]. The tension uniaxial behaviour of the concrete material was specified by Hognestad’s model by a factor of 1/10 [8]. The concrete damage plasticity factors (dilation angle, eccentricity, \( \epsilon_{00} / \epsilon_{c0} \), \( K \) and viscosity parameter) were taken as (35, 0.1, 1.16, 0.6667 and 0) respectively[1].
6. Finite Element results

The same specimens were analyzed using the finite element to compare the results with the push-out test results. Table 4 shows the result of FE.

Figure 9, Figure 10 and Figure 11 show comparison of the three specimens of load-slip relationship. Table 4 shows the ultimate load and the slip and the difference ratio between the experimental and numerical analysis, where the greatest difference ratio was 5.6% for ultimate load and 33.24% for slipping. It is considered a good and reliable result. Figure 12, Figure 13 and Figure 14 shows the deflection of models.

| Specimen | FE-ultimate load (kN) | Experimental ultimate load (kN) | Difference ratio of ultimate load | FE-Total slip (mm) | Experimental total slip (mm) | Difference ratio of slip |
|----------|-----------------------|--------------------------------|----------------------------------|-------------------|-----------------------------|-----------------------|
| D60C50   | 444                   | 439.831                        | 1%                               | 3.99              | 3.872                       | 3.05%                 |
| D30C50   | 279.01                | 264.026                        | 5.6%                             | 5.58              | 4.188                       | 33.24%                |
| D60C0    | 399.48                | 390.510                        | 2.3%                             | 2.70              | 2.457                       | 9.89%                 |

Figure 9 Load-slip relationship for the Specimen D60C50

Figure 10 Load-slip relationship for the Specimen D30C50
Figure 11 Load-slip relationship for the Specimen D60C0.

Figure 12 Failure mode of the Specimen D60C50.

Figure 13 Failure mode of the Specimen D30C50.
7. **Parametric study**

The behaviour of push out test depend on several parameters, such as the strength of concrete block, the strength of concrete filled steel tube, the length of the shear connector channel and the yield strength of the channel and the ultimate strength.

The parametric studies in this investigation were included various value of the parameters mentioned above on the specimen D60C50.

7.1 **Strength of concrete filled tube**

Different values of CFST strength were taken (40, 50, and 60 MPa) to study the of the of CFST to the ultimate load and the slipping. Figure 15 shows the load-slip relationship of the three different values of the strength of CFST which shows the curves match, it is obvious the strength of CFST has no effect on the load slip relationship.

7.2 **Strength of concrete block**

The strength of concrete block one of the most important factors influencing on the push-out test therefore, different values of concrete strength were taken (20, 30, 40, 50, and 60 MPa) for the purpose of the studying its effect.
When comparing the results, it was found that the relationship between the compressive strength of concrete and the loading of specimen was positive, in other words, increasing the strength of concrete leads to increasing the load and reducing the slip between the concrete and the steel tube surfaces at the test and vice versa shown in Figure 16, also observe that, the stiffness almost equally and unaffected at initial values.

![Figure 16 Load-slip relationship for various values of strength of concrete block](image)

7.3 The length of the shear connector channel
Different values of shear connectors channel length (50, 60, 70, 80, 90 and 100) mm were taken for the purpose of studying their effect on the push-out test.

Increasing the length of shear connector leads to an increase its resistance to shear force or failure. Therefore, we notice that when the length of the connector increases, the load at which the specimen fails will be higher and does not affect the amount of Slip at failure between the concrete and the steel tube surfaces as shown in Figure 17, also observe that, the stiffness almost equally and unaffected at initial values.

7.4 Yield stress of the steel channel
The yield stress of the steel channel one of the factors influencing the examination, we note that the relationship between the yield stress of the connector and the strength of the loading of specimen was positive, in other words, increasing the yield stress of the steel channel leads to increasing the load at the test and vice versa, and on effect on the slip between the concrete and the steel tube surfaces shown in Figure 18.

The increase of the yield stress of channel by 14% increased the loading of specimen by 4.73% and when reduced the yield stress of channel by 12.8% decreased the loading of specimen by 7.3%.
Figure 17 Load-slip relationship for various values of channel length

Figure 18 Load-slip relationship for various values of yield stress for channel

8. Conclusion
In this study, the experimental test and finite element model were adopted to analyze the behaviour of concrete filled steel tube with a shear connector channel by push-out test specimens where it turned out

1. The specimen of concrete filled steel tube was failed in higher load than the specimen of hollow steel tube which was failed by local buckling before the failure of the concrete block.
2. The strength of concrete block was an important factor, when the strength of concrete increases, the ultimate load increases in the push-out test. For example: when the strength of concrete increases form 50 MPa to 60 MPa, the ultimate load increases by 9.3 %.
3. The length of the channel effect on the results, when increases the length of shear connector channel that leads to an increase in the ultimate load in the test without effect on the slipping. For example: when the length of channel increases from 80 mm to 90, the ultimate load increases by 12.3 %.
4. Increasing the yield stress of the channel leads to increasing in the ultimate load in the test with no effect on the slipping. When increasing the yield stress of the channel from 344 MPa to 400 MPa, the ultimate load increases by 4.5 %.
5. the strength of CFST has no effect on the load slip relationship.

References
[1] ABAQUS. 2014 User's Manual, Ver. 6.14.
[2] BIBM, C. and E. ERMCO, EFNARC (2005) The European guidelines for self-compacting concrete. Specification, Production and Use.
[3] Bonilla, J., L.M. Bezerra, R. Larrúa, C.A. Recarey Morfa, and E. Mirambell Arrizabalaga, 2015 Numerical modelling with experimental validation applied to the study of stud connectors behaviour in concrete and steel composite structures. Revista de ingenieria de construcción (Online). 30(1): p. 53-68.
[4] Dai, X. and D. Lam, 2010 Numerical modelling of the axial compressive behaviour of short concrete-filled elliptical steel columns. Journal of Constructional Steel Research. 66(7): p. 931-942.

[5] Guezouli, S. and A. Lachal, 2012 Numerical analysis of frictional contact effects in push-out tests. Engineering Structures. 40: p. 39-50.

[6] Han, L.-H., W. Li, and R. Bjorhovde, 2014 Developments and advanced applications of concrete-filled steel tubular (CFST) structures: Members. Journal of Constructional Steel Research. 100: p. 211-228.

[7] Hognestad, E. 1951 Study of combined bending and axial load in reinforced concrete members, University of Illinois at Urbana Champaign, College of Engineering ....

[8] Huang, W., Z. Lai, B. Chen, Z. Xie, and A.H. Varma, 2018 Concrete-filled steel tube (CFT) truss girders: Experimental tests, analysis, and design. Engineering Structures. 156: p. 118-129.

[9] Lam, D. and E. El-Lobody, 2005 Behavior of headed stud shear connectors in composite beam. Journal of Structural Engineering. 131(1): p. 96-107.

[10] M-04, A.A.A. 2004 Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement, ASTM International West Conshohocken, PA.

[11] Nguyen, H.T. and S.E. Kim, 2009 Finite element modeling of push-out tests for large stud shear connectors. Journal of Constructional Steel Research. 65(10-11): p. 1909-1920.

[12] Oguejiofor, E. and M. Hosain, 1994 A parametric study of perfobond rib shear connectors. Canadian Journal of Civil Engineering. 21(4): p. 614-625.

[13] Pavlović, M., Z. Marković, M. Veljković, and D. Budjevac, 2013 Bolted shear connectors vs. headed studs behaviour in push-out tests. Journal of Constructional Steel Research. 88: p. 134-149.

[14] Rambo-Roddenberry, M. 2002 Behavior and strength of welded stud shear connectors, Virginia Tech.

[15] Shallal, M.A. Flexural behavior of concrete-filled steel tubular beam. in 2018 International Conference on Advance of Sustainable Engineering and its Application (ICASEA). 2018. IEEE.

[16] Shim, C.-S., P.-G. Lee, and T.-Y. Yoon, 2004 Static behavior of large stud shear connectors. Engineering structures. 26(12): p. 1853-1860.

[17] Spremic, M., Z. Markovic, M. Veljkovic, and D. Budjevac, 2013 Push-out experiments of headed shear studs in group arrangements. Advanced steel construction. 9(2): p. 139-160.

[18] Titoum, M., A. Mazoz, A. Benanane, and D. Ouinas, 2016 Experimental study and finite element modelling of push-out tests on a new shear connector of I-shape. Advanced Steel Construction. 12(4): p. 487-506.