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Influence of the steel tube thickness on the perfobond connectors load capacity

Abstract: Steel-concrete composite structures is one of the most explosive rapidly developing, cost-effective, and environmentally sustainable processes frequently utilised in high-rise structures and medium-span bridge decks. This research presents an experimental work to investigate the performance of a composite, concrete-filled steel tube (CFST) specimens manufactured by self-compacting concrete (SCC) under a push-out test. Ten CFST specimens have been considered in the experimental tests with a combined two concrete slab. Two variables have been considered in the experimental tests: thickness of tested tube (5 mm and 6 mm) and concrete slab strength (25, 35,45, 55, and 65 MPa). For comparison, all concrete slabs are made with normal concrete and steel tubes filled with SCC. The ultimate shear strength, load-slip behavior, failure load, crack pattern, and failure mode were studied. The experimental results present that the ultimate shear capacity and specimens stiffness improved by increased concrete block strength from 25 to 65 MPa. In addition, it was found, that at the slab concrete strength reduction from about 65 to 25 MPa, it decreased by 4.45%, 9.75%, 14.44%, and 18.34% for 5 mm tube thickness, however, for 6 mm thickness tested specimens, it decreased by 5.36%, 9.35%, 16.04%, and 19.6%, respectively. The specimen with the 6 mm-thick steel tube had better ultimate force capacity and specimens stiffness than the one with the 5 mm-thick tested tube. The perfobond rib is utilised as an effective shear connection in composite or hybrid structures due to its adequate ductility and enhanced shear capacity.

Keywords: CFST, compressive strength, perfobond connector, push-out test, self-compacting concrete.

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1. INTRODUCTION

The presence of numerous inferior bridges and increasing costs of labour led to the search for a novel bridge design that is economical, simple to construct, and durable. It was found, engineers have recognised the beneficial effects of infilling hollow steel sections with concrete [1, 2]. Concrete-filled steel tubular (CFST) columns exhibit superior structural behavior in comparison to steel columns or reinforced concrete (RC) columns, due to the encasement of the concrete within the tested tube afforded by the tested core-concrete, which delays local buckling of the tube due to restraining influence of the strength concrete. This CFST column system has several benefits, including: 1) making the building more efficient by getting rid of the need for formwork, which saves time, money, and labour; 2) making the building more fire-resistant thanks to the infilled concrete; and 3) reducing damage to the environment by not using formwork. The combined use of steel components and concrete for the producer of structural composite beams in buildings has progressed throughout the years. This method is often employed in tall buildings and medium-span bridge decks due to its speed, affordability, and environmental friendliness. The benefits of each steel girder and concrete part are incorporated in steel-concrete composite structures, which combine the inherent mass, stiffness, damping, and cost-effectiveness of concrete with the strength, and lightweight nature of steel. A new sort of composite structures is combined of a concrete block connected to steel beams by ultilized shear connections. Research on stud shear connections has included push-out of tested beam to assess shear capabilities [3-6]. There are many connectors, such as perfobond, T-perfobond, corrugated shear, oscillating-perfobond strip shear, perfobond ribs, and waveform-strip shear. commonly shear connections in composite structures include highlighted studs and short channels [7, 8]. The head stud serves as the primary shear connection employed in combination steel beams to concrete part structures for minimising horizontal shear force and vertical uplift loads. The installation of headed studs demands specialised machines and experienced operators, resulting in additional costs that could offset the benefits of composite beams. Nevertheless, the head stud shape might create cracking in the surface concrete block and sustain fatigue under operational stress situations. One of the recent innovations in shear connections is the perfobond-rib shear connector, which is characterised by its high shear resistance capability, simplified installation related to the rib setup, and enhanced fatigue resistance. A perfobond-rib shear connection, created in Germany, includes a flat plate with several holes. This connector withstands horizontal shear and vertical uplift pressures at the composite specimens interface through utilising the installation of a bearing zone, concrete dowels, and web rods within the rib openings [9]. The smooth flow of concrete across the rib openings formed dowels that offer resistance in both vertical and horizontal orientations. Research on the shear capacity and behaviour of the perfobond rib has been performed using push-out tests, and numerical modelling [10-15].

Numerous experimental works have been conducted to quantify the push-out tests for composite samples strengthened by perfobond-rib shear connector. Ahn et al. in [16] assessed the efficacy of the perfobond-rib shear connection within the structure of concrete and steel combination girder bridges. The test findings are compared to analyses of the end-bearing concrete area, the longitudinal reinforcement within the rib opening, and the ultimate strength designation equations associated with perfobond ribs. The push-out testing demonstrate a clear correlation between the concrete's capacity and the ultimate shear resistance of the perfobond-rib shear connection. The shear performance of a double perfobond-rib shearing connector is around 80% inferior to that of simply one perfobond rib. The reduced strength in shear is attributed to the concrete end-bearing region, the concrete dowel, and the longitudinal rebar within the rib opening. In addition, the experimental tests of Zheng et al. [17] have revealed that a crack initially develops at the perfobond shear connections span over the concrete block. The rebar in the opening shows bending at the perforated sites due to substantial stresses. The concrete dowels within the opening demonstrate shear failure. Further, the experimental tests of Li et al. [18] have demonstrated that the shear stiffness of the concrete rods is the main variable influencing the elastic stage, which is the total shear rigidity of the corrugated rib connector. On the other hand, during the elastic-plastic stage, the shear rigidity of the concrete rods and perforated rod substantially influences the overall shear strength of the corrugated rib connection. Zheng et al. [19] investigated the impact of push-out modes of failure of the perfobond rib utilizing the headed stud mixed shear connection, characterized by studs shank rupture, concrete crushing under the stud root, yielding of the perforating rebar, and simultaneous concrete dowel shear. The shear strength of the composite shear connector is increased by a rise in stud size, rebar dimensions, hole measurement stud strength, rebar ability, and strength of the concrete. Zheng et al. presented a study on the ultimate shear force of a perfobond shearing connection [20]. The failure mechanisms of circular-hole and long-hole perfobond connections have been determined by concrete failure. They found that the shear strength of the perfobond connection grows with an increase in hole diameter and hole height. Ibrahim et al. [21] assessed an experimental investigation on beam sections made of steel tubes as an alternative to I-sections. Results from experiments indicated that the existing design formulas for studs, angles, and perfobond connections with I-sections are applicable for calculating the shear resistance of connectors with composite steel tube sections. Many of the analyzed studies focused on the push-out testing of reinforcing regular vibrated concrete (NVC) instead of self-compacting concrete (SCC).

Based on the previously mentioned studies, it is obvious that there are extremely few experimental investigations that have studied the behavior of normal concrete concrete-filled steel tube (CFST) connected by a perforated-rib shear connector between steel and concrete slab. In addition, no experimental study has been conducted on perforated connector holes in slip and horizontal shear resistance for CFST specimens made with self-compacting concrete (SCC). Therefore, further experimental investigations in this area are necessary. This study aimed at examining the perforated concrete composite specimens consisting of CFST and made with a variety of strength SCC mixes. A series of CFSTs made with SCC specimens were prepared and tested until failure. The beams' behaviour was evaluated in terms of ultimate failure stress, shear resistance, load-slip response, and cracking morphology.

2. EXPERIMENTAL WORK

2.1. SPECIMENS PREPARATION

In this work, ten CFST composite sample were testing until failure. The main variables altered in the test procedures: the thickness of the tested tube and the compressive slab concrete strength. Based on the thickness of their steel tubes, categorised the tested composite specimens into two groups. The first group of five CFST column specimens was made with dimensions of 5 mm thick, 500 mm long, and a cross-section of 150 × 150 mm. This group begins with the name of the specimens "S5". The second group consists of five specimens that were 6 mm thick. This group is named S6. All specimens comprise two reinforced concrete blocks with dimensions of 450 × 100 mm cross-section and 500 mm length. The concrete slab was made with normal concrete; nevertheless, the tube was filled with self-compacting concrete (SCC). The cubic strength of the self-compacting concrete mixture used as filling of the tubes remained similar for each specimen. The designation of the tested specimens is present in Table 1. Table 2 shows the specimen details. "S" represents the stand shape for square tubes. The numbers 5, 6 indicate the tubes' thickness. Conversely, two normal concrete tested slabs were fabricated in a horizontal orientation, as is conventional of composite beams in application. Concrete slabs have been reinforced with two layers of rebar. These specimens are connected to the concrete block on both sides by a perfobond connector. The perfobond connector measures 450 × 60 × 10 mm, with 12 mm diameter holes to insert the steel reinforcing bar into each section. The perfobond connector and steel tube were connected by welding.

Table 1. Identification of the tested CFST specimens

Sample designation	Sample details
S5-25	Square tube + 5 mm tube thickness + 25 MPa compressive strength for concrete slab
S5-35	Square tube + 5 mm tube thickness + 35 MPa compressive strength for concrete slab
S5-45	Square tube + 5 mm tube thickness + 45 MPa compressive strength for concrete slab
S5-55	Square tube + 5 mm tube thickness + 55 MPa compressive strength for concrete slab
S5-65	Square tube + 5 mm tube thickness + 65 MPa compressive strength for concrete slab
S6-25	Square tube + 6 mm tube thickness + 25 MPa compressive strength for concrete slab
S6-35	Square tube + 6 mm tube thickness + 35 MPa compressive strength for concrete slab
S6-45	Square tube + 6 mm tube thickness + 45 MPa compressive strength for concrete slab
S6-55	Square tube + 6 mm tube thickness + 55 MPa compressive strength for concrete slab
S6-65	Square tube + 6 mm tube thickness + 65 MPa compressive strength for concrete slab

Table 2. Details of tested CFST composite specimens

Specimen name	Shape	Tube thickness [mm]	Tube height [mm]	Cross-section tube [mm^2]	Cross-section concrete slab [mm^2]	Height of concrete slab [mm]	Compressive strength [MPa]	
							SCC-CFST	Concrete slab
S5-25	Square	5	500	150 × 150	450 × 100	500	25	20
S5-35	Square	5	500	150 × 150	450 × 100	500	35	20
S5-45	Square	5	500	150 × 150	450 × 100	500	45	20
S5-55	Square	5	500	150 × 150	450 × 100	500	55	20
S5-65	Square	5	500	150 × 150	450 × 100	500	65	20
S6-25	Square	6	500	150 × 150	450 × 100	500	25	20
S6-35	Square	6	500	150 × 150	450 × 100	500	35	20
S6-45	Square	6	500	150 × 150	450 × 100	500	45	20
S6-55	Square	6	500	150 × 150	450 × 100	500	55	20
S6-65	Square	6	500	150 × 150	450 × 100	500	65	20

2.2. SPECIMENS DESIGNED AND REINFORCEMENT DETAILS

This study involved the manufacturing of perfobond-rib specimens according to the standard push-out test outlined in Eurocode-4 [22]. This experimental test was performed to evaluate the shear behaviour of perfobond-rib shear connectors respecting concrete's strength and rib design. The measured dimensions and configuration of the push-out samples were similar to allow for a comparison of the ultimate shear strength of specimens and slip resistance force. Therefore, the experimental procedure of this study involved casting and performing push-out tests on reinforced SCC-CFST columns with NC deck slab dimensions of 450 mm width, 150 mm height, and 150 mm length. Fig. 1 illustrates the details of the examined composite specimens. Fig. 1 also exhibits two layers of reinforcement of steel rods with diameter of 10 mm, arranged at 150 mm intervals in both transverse and longitudinal directions to strengthen the concrete tested blocks. The concrete cover from the top and bottom was 8 mm, whereas the concrete cover from the sides was 10 mm.

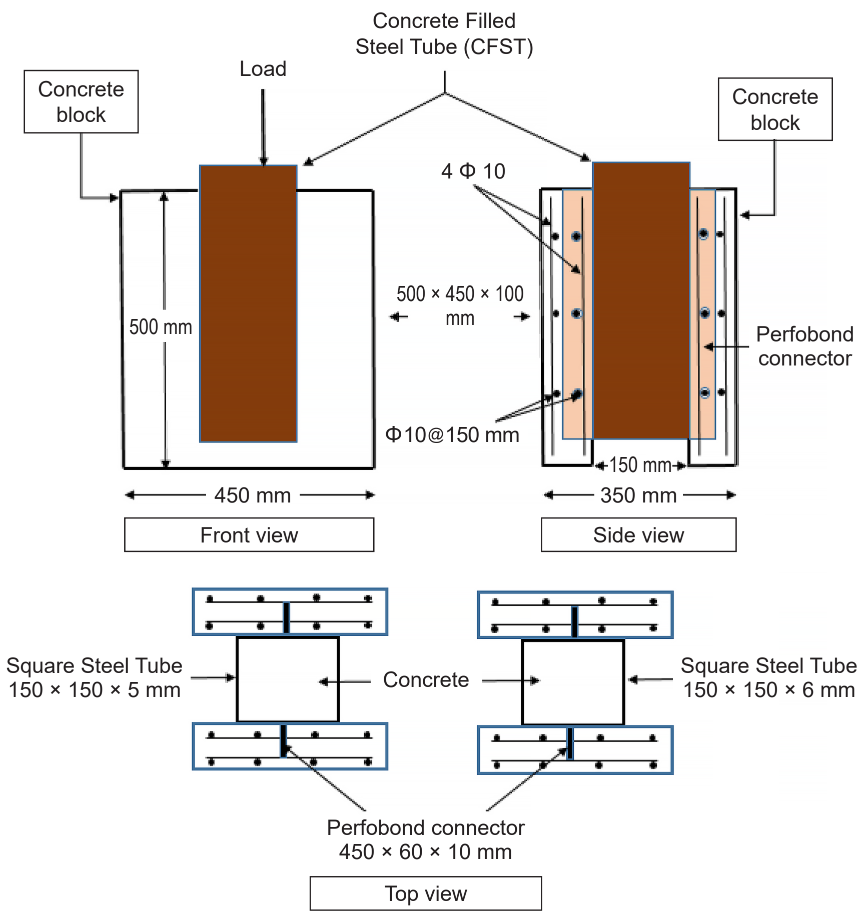


Fig. 1. Details of tested CFST composite specimens

2.3. MATERIALS

All the concrete mixes in this investigation used ordinary Portland cement obtained from the local market. It satisfied to the criteria of the Iraqi Standards (IQS) [23]. Limestone powder (LP) with particles smaller than 0.125 mm was used to increase the amount of fine components. This procedure made the mix more fluid and consistent and less likely to separate, as required by EFNARC criteria [24]. Two sorts of aggregates, fine and coarse, having a maximum size of 4.75 and 20 mm, respectively, were used Fig. 2. Natural sand was utilized as the fine-type aggregate, while gravel performed as the coarse aggregate sort in all the concrete mixtures used to cast normal and SCC concrete-filled steel tube columns. The physical characteristics of fine aggregate were evaluated at the Structural Lab of the Engineering Department Consulting Office at the College of Engineering, Al-Qadisiyah University. Further, a locally available, crushing coarse aggregate type having an optimal nominal size of 19 mm was utilized. All aggregate was used in saturated surface dry conditions (S.S.D). All types of aggregate conform with the IQS [25]. Fig. 2 presents the sieve analysis of this aggregate. A superplasticizer (SP) was used as in this investigation. It satisfies the ASTM C-494 type F specification. The present research employed deformed steel bars having dimensions of 10 mm to strengthen the concrete tested slab. The direct tensile specimens strength of three specimens was performed in accordance with ASTM A615-05 [26]. Table 3 presents the mechanical characteristics of these bars. To calculate the mechanical properties of the steel tubes, the Computer Numerical Control (CNC) machine cut three tension dog bones (steel tubes) from the web. The dog bones conform to ASTM A 36/A 36M standards [27].

Table 3. Properties of the used steel

Component	Yield stress F_y [N/mm²]	Ultimate strength F_u [N/mm²]
Square tube 150 × 150 × 6 mm	400	450
Square tube 150 × 150 × 5 mm	380	420
Steel reinforcement bar ϕ10 mm	465	610
Perfobond connector t = 10 mm	380	400

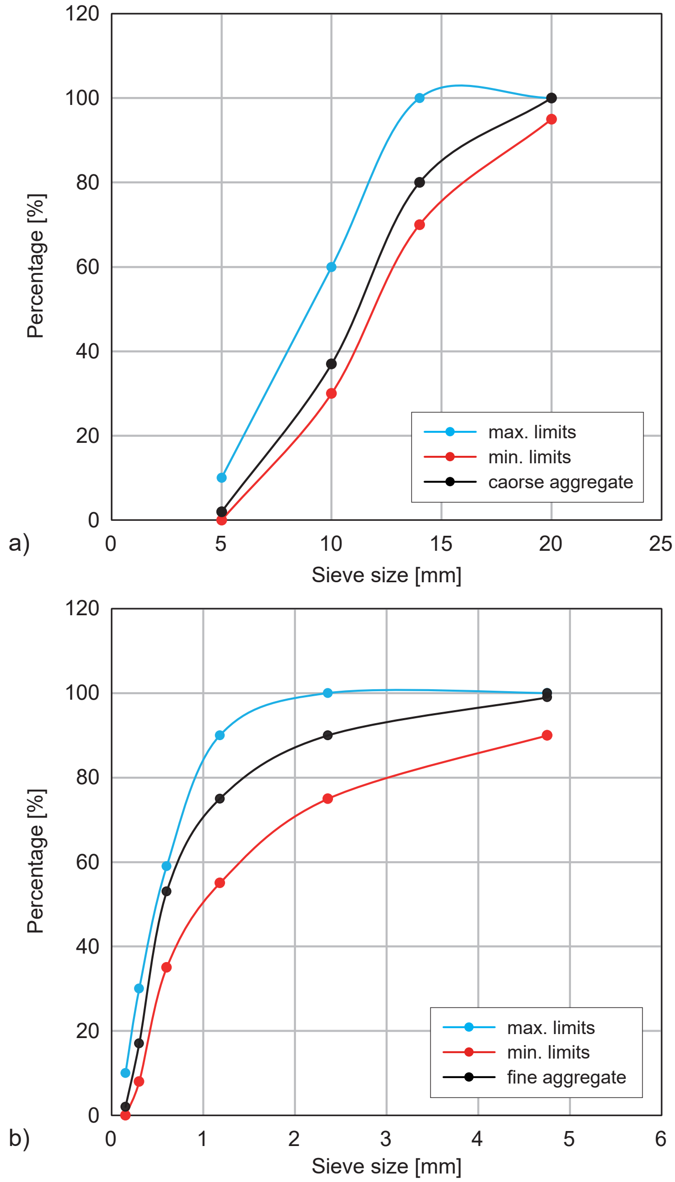


Fig. 2. Sieve analysis of: a) gravel (coarse aggregate), b) sand (fine aggregate) [25]

2.4. MIX PROPORTION OF NORMAL CONCRETE AND SELF-COMPACTING CONCRETE

Normal concrete (NC) mixtures have been designed with various water-to-cement w/c ratios varying from 0.25 to 0.55, using coarse and fine aggregates in S.S.D. state. The components of the produced mixtures were assigned according to a rational mix design methodology specified in the American Concrete Institute's mixing ratios (ACI 211.1-01) [28]. Table 4 presents the combined ingredients of all investigated mixes. Conversely, one SCC mix achieved a nominal compressive strength of 22 MPa after 28 days, which corresponds to a water-to-cement ratio *w/c* of 0.3. The design utilized the reasonable and direct mix proportioning approach described in ACI 237R-07 [29]. In the preparation of the SCC mix, coarse aggregates, in saturated surface dry conditions, were utilised. The outcomes revealed that the specimen's densities extend between 2200 kg/m^3 and 2740 kg/m^3. Moreover, the maximum compressive strength F_{cu} was 66 N/mm^2, and the minimum F_{cu} was 22 N/mm^2.

cracks. Two "Linear Variable Differential Transformers" (LVDTs) were strategically positioned to determine the deformation during the test. Fig. 3 illustrates the placement of these LVDTs. Both LVDTs will provide the essential data for analysing the connector's response to varying loads. The load was applied incrementally in 5 kN intervals. The experimental procedure strictly adhered to the standards specified in Eurocode 4 [22], ensuring the reliability of the results.

Table 4. Components of the produced concrete mixtures [kg/m^3]

Mix type	Ratio of mixing	*w/c*	Limestone powder LP [g]	Super-plasticizers [%]	Compressive strength F_{cu} [N/mm^2]	Density [kg/m^3]
Self-compact concrete SCC = 20	1 : 1.75 : 0.6	0.3	151	1	22	2200
Normal concrete M1 = 65	1 : 1.25 : 2	0.25	–	0.6	66	2740
Normal concrete M2 = 55	1 : 1.50 : 2.25	0.3	–	0.5	55.16	2517
Normal concrete M3 = 45	1 : 1.85 : 2.80	0.4	–	0.3	47.92	2341
Normal concrete M4 = 35	1 : 2.70 : 4.25	0.5	–	–	35.14	2280
Normal concrete M5 = 25	1 : 3.25 : 4.75	0.55	–	–	26	2250

2.5. CONCRETE SPECIMENS CASTING AND CURING

Ten CFST composite specimens were fabricated in the present study. For casting specimens, a vertically portable mixture having a mixing capacity of 0.2 m^3 was utilized for blending fresh ordinary concrete and self-compacting concrete (SCC). Firstly, the column samples were cast with SCC mixes, and the models' top surfaces were adjusted. The concrete slab samples were cast with normal concrete, and the mold's top surfaces were adjusted. To evaluate the experimental mechanical characteristics of the cast mix, cast cube, cylinder, and prism specimens for every beam specimen. The formworks were removed after 21 days, and the research samples were wrapped in polypropylene sheets to maintain a semi-controlled condition until the appropriate age was obtained.

2.6. TEST PROGRAMME

The performance evaluation of perfobond connectors was conducted through a push-out test aimed at measuring displacement between CFST and concrete blocks. The instrumentation was accessed in the Structural Lab of the Civil Engineering and Construction Department at Al-Qadisiyah University. As illustrated in Fig. 3, the tested composite samples had been painted two days prior to testing for easier observation of the developed and propagated

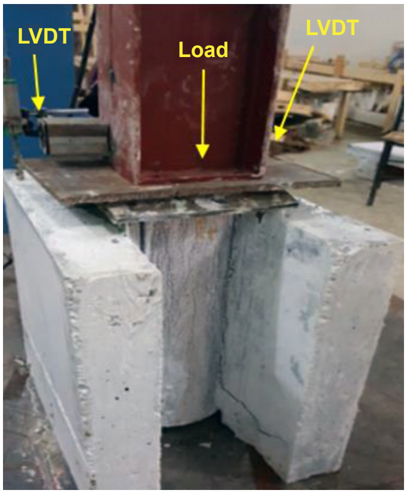


Fig. 3. The used hydraulic testing machine

3. ANALYSIS AND DISCUSSION

3.1. PUSH-OUT TEST

Ten reinforced composite CFST specimens made with NC and SCC concrete were prepared to investigate their structural behaviour. Five reinforced composite specimens were made with 5 mm-thick steel tubes; however, the others were made with 6 mm-thick tubes. Table 5 and Fig. 4 summarises the experimental push-out test results for the column specimens, including their ultimate capacities, failure loads, and slip resistance values. The following sections discuss and evaluate the results and the interrelation between load and slip for each specimen.

Table 5. Experimental results for push-out tested composite CFST specimens

No.	Specimens designation	Thickness of tube t [mm]	Ultimate shear capacity V_u [kN]	Increase in shear strength [%]	Elastic shear strength V_y [kN]	Elastic slip S_i [mm]	Maximum slip S_P [mm]	Stiffness of elastic stage K_s [kN/mm]
1	S5-65	5	640.50	–	300	1.40	4.50	214.28
2	S5-55	5	612.00	3.90	260	2.00	6.90	130.00
3	S5-45	5	578.00	–	245	2.30	8.40	106.52
4	S5-35	5	548.00	3.04	228	2.50	10.10	91.20
5	S5-25	5	523.00	–	160	2.70	12.00	59.25
6	S6-65	6	667.00	4.44	400	0.70	3.00	571.42
7	S6-55	6	631.20	–	330	1.40	5.20	235.71
8	S6-45	6	604.60	2.14	250	1.60	6.50	156.25
9	S6-35	6	560.00	–	240	1.80	8.10	133.33
10	S6-25	6	536.20	2.46	170	2.00	10.20	85.00

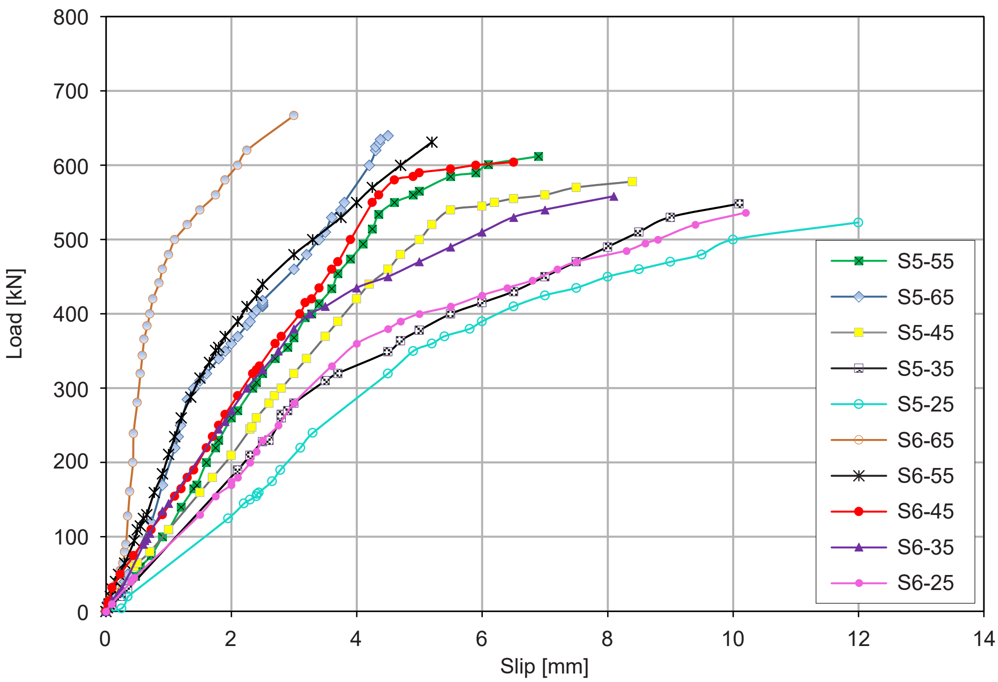
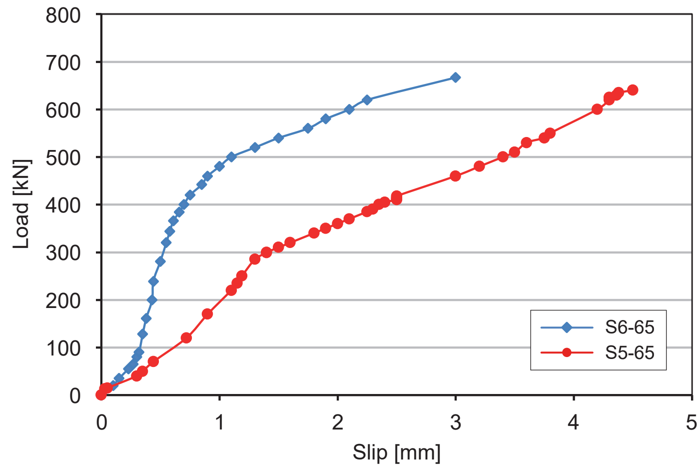


Fig. 4. Specimens load-slip relation

3.2. EFFECT OF STEEL TUBE THICKNESS

Analysing the relationship between slip and applied load for each composite CFST specimen was part of the testing method. The load slip behaviour is shown in Fig. 4 for all specimens. The first group includes five composite CFST samples designated as S5-65, S5-55, S5-45, S5-35, and S5-25, which have the same spacing of thickness tube (5 mm) but different concrete strength, as shown in Table 5. The test samples S5-65 have a maximum shear strength of 640.5 kN, a 300 kN elastic shear strength, 1.4 mm of elastic slip, and 4.5 mm of maximum slip. Furthermore, the stiffness of the S5-65 and S6-65 specimens, respectively, was higher than that of the reference-tested samples. The maximum shear capacity of the S5-55, S5-45, S5-35, and S5-25 specimens is 612, 578, 548, and 523 kN, which is about −4.44%, −9.76%, −14.44%, and −18.35% less than the control CFST columns (S5-65 specimens), with a corresponding elastic slip of 2, 2.3, 2.5, and 2.7 mm, respectively. Regarding the second group with a 6 mm thickness tube, it was obviously observed that these CFST composite specimens exhibited a lower stiffness than those of reference composite specimens. The decrease was about 5.37%, 9.42%, 16.04%, and 19.61% for other tested samples (Table 5).On the other hand, the influence of changing the thickness of the CFST specimens on the load-slip behaviour of perfobond connectors was explored. Analysis of the results presented in Table 5, Fig. 5 and Fig. 6 reveals discernible trends regarding the impact of varying specimen thickness on ultimate shear strength and stiffness. The thickness variation notably influences the specimens' stiffness.



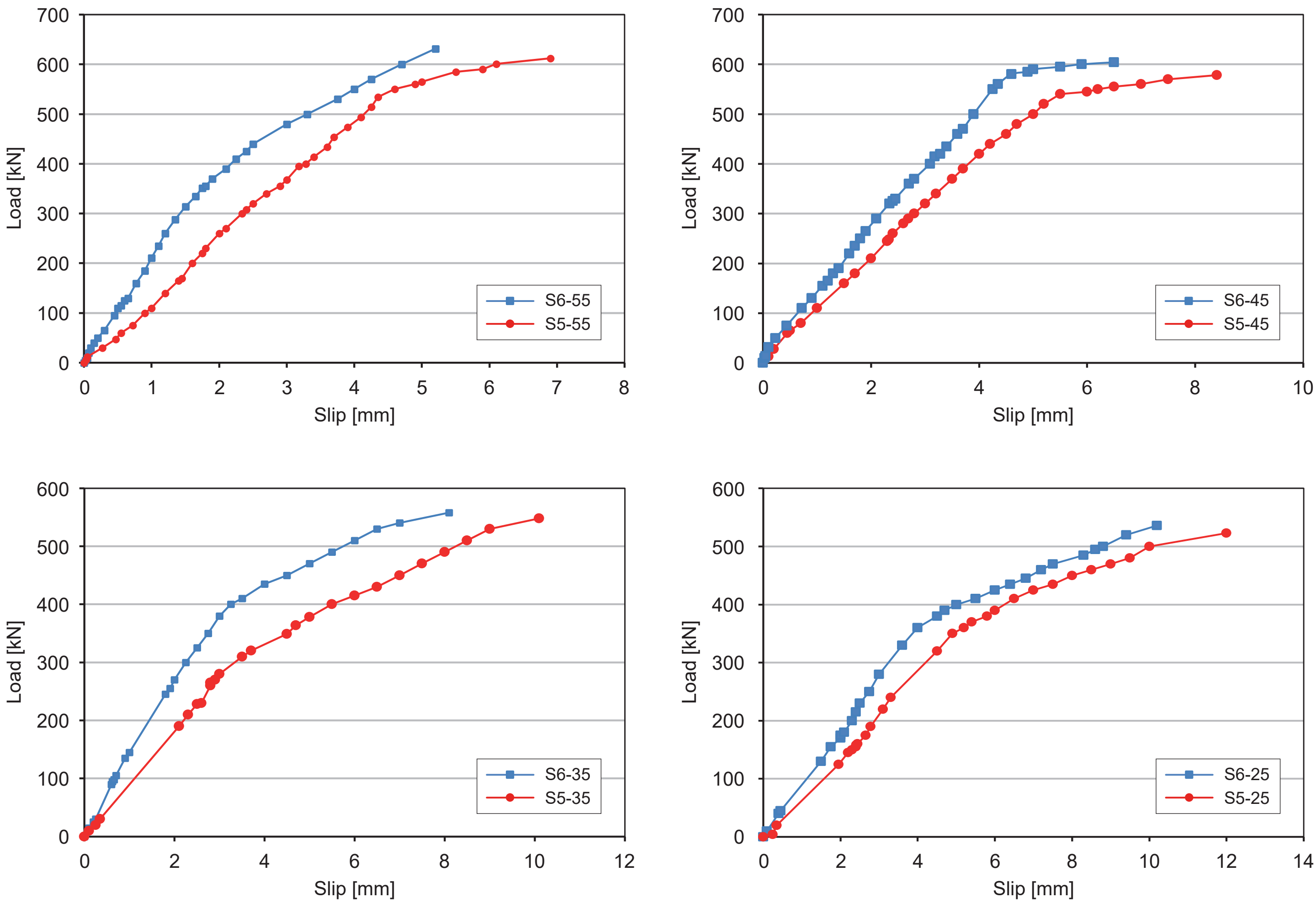
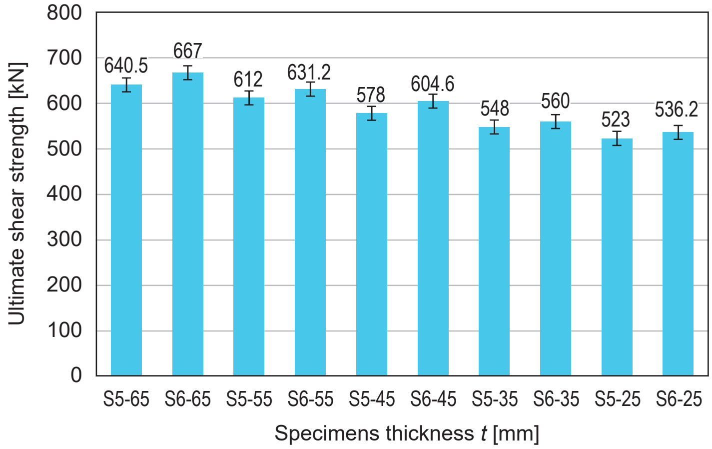


Fig. 5a. Effect of CFST thickness on the load-slip behaviour →



← Fig. 5b. Effect of CFST thickness on shear strength

For 5 mm tube thickness, the stiffness ranges from 214.28 kN/mm to 59.25 kN/mm, while for 6 mm tube thickness, it varies from 571.42 kN/mm to 85 kN/mm, as shown in Fig. 6. It is obvious from the experimental results that there is a positive correlation exhibited between the specimens' ultimate shear strength and stiffness as the steel tube thickness increases. The thicker the tube, the better the confining effect of the concrete, which increases its effective stiffness and reduces the possibility of local buckling of the tested tube, which increases the efficiency of the section. These outcomes revealed the significance of the thickness of the tube in terms of determining the performance of the structure of CFST elements.

The major outcome from this study for the 5 mm thickness specimens of CFST was the ultimate shear strength decreased by 4.45%. The normal concrete strength of blocks dropped from 65 to 55 MPa, by 9.75%. On the other hand, the normal concrete strength of side blocks was further reduced to 45 MPa, 35 MPa, and 25 MPa; the percentage fell by 9.75%, 14.44%, and 18.34%, respectively. The 6 mm thickness specimens of CFST presented a reduction in the ultimate shear strength by 5.36%, 9.35%, 16.04%, and 19.6% when the normal concrete block strength was reduced from 65 to 25 MPa, abatement each 5 MPa. The stiffness of the tested specimens with a thickness of 5 mm decreased by 39.33% when the concrete blocks' strength was reduced from 65 to 55 MPa. When the regular concrete blocks strength was further reduced to 45 MPa, a further drop of 50.28% was noted. Further, the concrete strength was reduced from 45 MPa to 35 MPa, the stiffness dropped to 57.43%, and when it was reduced from 35 to 25 MPa, it dropped by 72.34%. The stiffness of the tested specimens with a thickness of 6 mm decreased by 58.75% when the concrete blocks' strength was reduced from 65 to 55 MPa. Additionally, the blocks strength was further dropped to 45 MPa, a reduction of 72.65% was noted. Stiffness decreased by 76.66% when the concrete slab strength was further reduced to 35 MPa and by 85.12% when further decreased to 25 MPa. In general, the maximum slip falls as concrete strength increases. The maximum slip for specimens with a 5 mm steel tube thickness is 4.5, 6.9, 8.4, 10.1, and 12 mm, depending on the concrete's compressive strength of 65, 55, 45, 35, and 25 MPa. The maximum slip for specimens with a 6 mm steel tube thickness is 3, 5.2 mm, followed by 6.5 mm, 8.1 mm, and 10.2 mm when the concrete's strength is 65, 55, 45, 35, and 25 MPa.

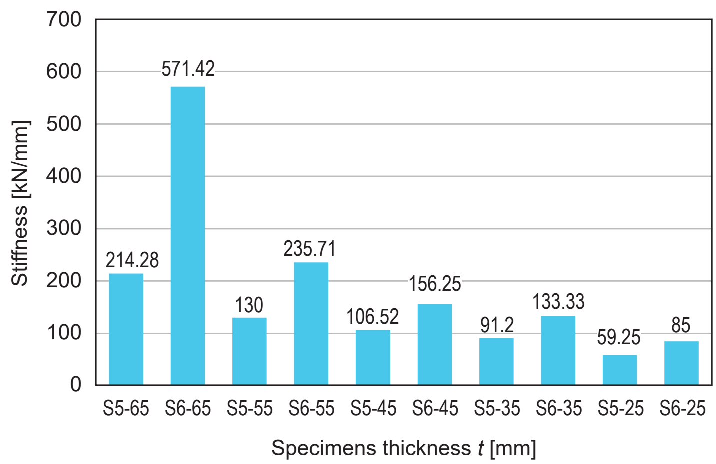


Fig. 6. Influence of the CFST tube thickness on stiffness

3.3. EFFECT OF CONCRETE SLAB COMPRESSIVE STRENGTH ON SHEAR STRENGTH

This study investigates the variables effecting the concrete slab strength for side slabs as considered a pivotal parameter. The impact of normal concrete slab strength on the load-slip curves for (CFST) specimens is presented in Fig. 7. The results manifest a discernible trend wherein an increase in concrete strength correlates positively with an augmentation in the ultimate shear strength. Specifically, the maximum shear strengths for specimens S6-65, S6-55, S6-45, S6-35, and S6-25 are observed to be 667 kN, 631.2 kN, 604.6 kN, 560 kN, and 536.2 kN, respectively. This trend underscores a notable correlation between concrete strength and the structural capacity to resist shear forces. However, it is imperative to note that an inverse relationship is observed between regular concrete slab strength and the maximum slip exhibited by the specimens. The results indicated maximum slips for the examined specimens as 3 mm, 5.2 mm, 6.5 mm, 8.1 mm, and 10.2 mm, respectively. It is evident as the block strength of concrete increases when the maximum slip decreases. The stiffness of elastic stage (Ks), as delineated in Table 5, reveals a consistent pattern across specimens S6-65, S6-55, S6-45, S6-35, and S6-25, with stiffness values of 571.42 kN/mm, 235.71 kN/mm, 156.25 kN/mm, 133.33 kN/mm, and 85 kN/mm, respectively. These outcomes assert that an escalation in concrete slab strength is associated with stiffness escalation of the elastic stage. A noticeable analogous trend in specimens, where an increase in compressive slab strength of concrete led to a corresponding rise in ultimate shear strength. The specimens' ultimate shear strengths are recorded as 523 kN, 578 kN, 612 kN, and 640.5 kN. At the same time, a reduction in maximum slips occurred when the concrete strength of concrete increased, with the recorded values of 4.5 mm, 6.9 mm, 8.4 mm, 10.1 mm, and 12 mm, respectively. Additionally, the stiffness values for the elastic stage display a consistent increase, affirming the positive correlation between normal blocks strength and both stiffness and ultimate shear strength. The obtained evidence from the empirical outcomes offered unequivocally establishes that any increase in the compressive strength of concrete positively correlates with an increase in the ultimate shear strength and stiffness of CFST. This provides insight into the significance of the implications of the structural practices, emphasising considering the concrete strength of concrete as a vital factor in the analysis and design of CFST.

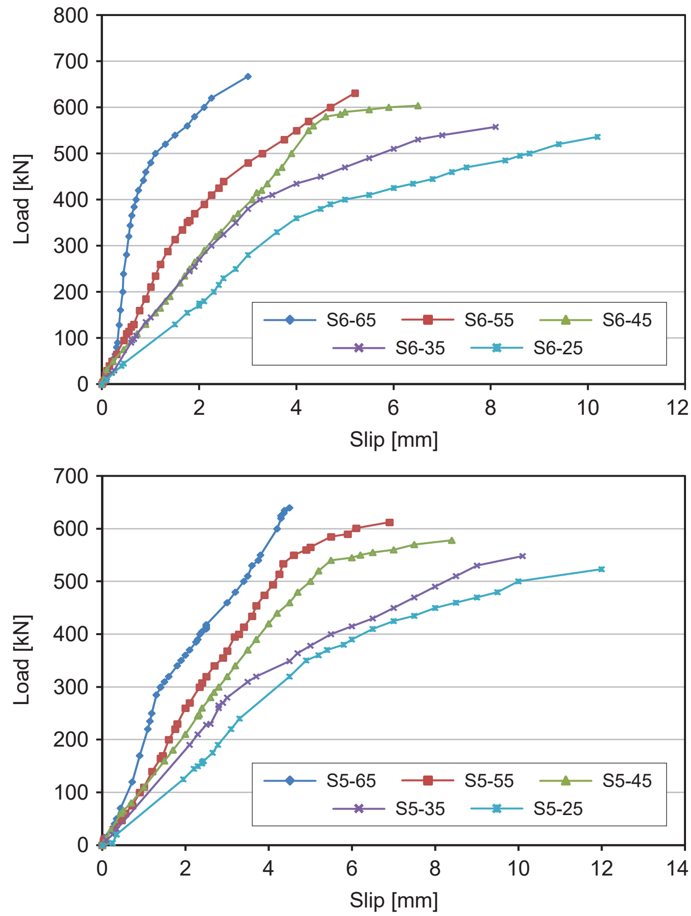


Fig. 7. Effect of the concrete slab strength on shear capacity

3.4. CRACK PATTERN AND FAILURE MODE

Distinct indicators were observed in specimens subjected to the ultimate load that achieved the failure stage. The observed signs in the specimens were unequivocal proof of reaching the failure and indicated the need for further analysis. The concrete has been extracted from both blocks to conduct the investigation in-depth. Furthermore, the reinforcing steel was disassembled from the connector. The taken-out reinforcing steel from the connector, as illustrated in Fig. 8, revealed the fate that was achieved for the bars. Based on the photo taken for the bars, it became apparent that some had been cut, while the rest exhibited deformation. The cutting and deformation results of the extracted reinforcing steel lead to understanding the mechanisms that forces followed during the failure mode.

Fig. 8. Bars deformations

4. CONCLUSIONS

This research delineates and examines a lab study into the performance and failure mode of composite CFST columns samples. The experiment's results lead to the following conclusions:

1. The shear concrete slab strength of the perfobond rib improved with concrete's block strength, due to the increased effect of both the end-bearing concrete region and the concrete slab strength.
2. The ductility-index of the perfobond-rib shear connecting required the flexibility standards of the longitudinal rod on the slab and correlated with changes in concrete slab strength.
3. The shear slab strength for 5 mm tube thickness decreased by 4.45%, 9.75%, 14.44%, and 18.34% when the concrete slab strength was gradually decreased from 65 to 25 MPa, respectively.
4. Ultimate shear capacity of the 6 mm thickness tested specimens decreased by 5.36%, 9.35%, 16.04%, and 19.6% when the blocks' concrete block strength was reduced from 65 to 25 MPa, respectively.
5. The specimen with the 6 mm-thick steel tube had better ultimate shear specimen's strength and stiffness than the one with the 5 mm-thick steel tube.
6. Stiffness of the tested 5 mm specimens decreased by 39.33%, 50.28%, 57.43%, and 72.34%; however, specimens with 6 mm thickness have dropped by 58.75%, 72.65%, 76.66%, and 85.12% when the concrete blocks' compressive specimens strength was reduced from 65 to 25 MPa, respectively.
7. The maximum slip of CFST columns is inversely proportional to the concrete slab strength, regardless of the thickness of the column specimens tested.

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Wpływ grubości ścianki rury zespolonej na nośność łączników typu perfobond

Streszczenie: Stalowo-betonowe konstrukcje kompozytowe są jednym z najszybciej rozwijających się, efektywnych cenowo i ekologicznych rozwiązań często stosowanych w wysokich budynkach i mostach o średniej rozpiętości. W artykule przedstawiono wyniki badań eksperymentalnych push-out (wytrzymałości na docisk przy uwzględnieniu ścinania), słupów zespolonych stalowo-betonowych, wypełnionych betonem (CFST, ang. *Concrete-Filled Steel Tube*), wykonanych metodą betonu samozagęszczalnego (SCC, ang. *Self-Compacting Concrete*). W badaniach uwzględniono dziesięć próbek CFST umieszczonych pomiędzy płytami żelbetowymi. W eksperymencie rozpatrywano dwie zmienne: grubość ścianki profilu stalowego (5 mm i 6 mm) oraz wytrzymałość płyt betonowych (25, 35, 45, 55 i 65 MPa). Wszystkie płyty betonowe wykonano z betonu zwykłego, natomiast stalowe rury wypełniono SCC. Celem badań było określenie wytrzymałości na ścinanie, wyznaczenie charakterystyk obciążenie-poślizg, obciążenia niszczącego, schematu pęknięć i formy zniszczenia. Wyniki eksperymentu wykazały, że zwiększenie wytrzymałości płyt betonowych z 25 do 65 MPa powoduje wzrost nośności na ścinanie i sztywności wciskanych próbek. Ponadto stwierdzono, że w przypadku profili metalowych o grubości ścianek 5 mm, zmniejszenie wytrzymałości z 65 do 25 MPa powoduje spadek nośności odpowiednio o 4,45%, 9,75%, 14,44% i 18,34%; natomiast dla próbek o grubości 6 mm odpowiednio o 5,36%, 9,35%, 16,04% i 19,6%. Próbka zespolona, w której grubość ścianki wynosiła 6 mm miała lepszą nośność i sztywność niż próbka, w której grubość miała wymiar 5 mm. Łączniki typu perfobond są wykorzystywane jako efektywne połączenie w konstrukcjach kompozytowych lub hybrydowych ze względu na większą odkształcalność w zakresie plastycznym i zwiększoną nośność na ścinanie.

Słowa kluczowe: beton samozagęszczalny, łącznik perfobond, próba push-out, wytrzymałość na ściskanie, zamknięte profile stalowe wypełnione betonem (CFST).