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Push Out Tests of Cold Formed Steel and Concrete Slab

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ملخص البحث

انتشرت فى السنوات الاخيرة استخدام الكمرات المركبة من قطاع معدنى مشكل على البارد وبلاطة خرسانية ويتنوع رابط القص الذى يربط بينهما فقد تم فى هذا البحث عمل اختبارات دفع لانواع مقترحة لهذا الرابط ويكون ذات تشكيل سهل فى التصنيع وقد بينت النتائج زيادة فى الحمل الاقصى لروابط القص المقترحة وكذلك كفاءة رابط القص المقترح.

Abstract

This work presents the push out tests which were carried out to examine shear transfer between the concrete slab and the cold formed beam section (CFS). Four push out tests were carried out under axial loading. The parametric studies were performed to investigate variations in shear dowel shape, taken into account the effect of bent up half flange channel as a new shear dowel. The results showed that the bent up half flange channel gave an increase of the ultimate load and improvement of shear transfer between the concrete slab and the steel section.

Keywords: Composite; Cold-formed; Push-out test; Bent-up half flange channel, as dowels.

1. Introduction

Cold-formed steel sections (CFS) are members which have lightweight that their structural performance is very high and suitable for building construction. Traditionally, they can be used as purlins and side rails in enveloping industrial buildings. The most famous cold-formed steel sections are the lipped C, and the Z sections. The thicknesses of these sections typically diverse from 0.9 mm to 3.2 mm [1]. The yield stress of these sections is universally between 280 to 450 N/mm^2 [2]. The use and significance of the CFS is expanding in the present construction due to its privileges of lightness and cost effective. One of the environmental popular advantages in CFS sections are its construction material for low rise residential and medium rise commercial buildings [3]. The majority of using CFS as construction members has enhanced more research to be conducted as composite structures. Composite structures exist when different components (i.e. steel and concrete) are connected to act as a single unit. The composite structure has so high hardness and load bearing capacity due to the composite action when they are compared with their non-composite counterparts [3-6]. The composite action happens when shear transfer mechanism should be combined by using enhanced shear connectors such as headed studs shear connectors [6]. So, the steel-concrete composite is harder and stronger than the steel and the concrete slab alone [7-11].

2. Previous Work

In modern years, owing to big structural efficiency, increased composite construction is used because it produces great reduction of structural elements and also reduction of floor height. The cast concrete for cold formed steel section, keeps it in fire case. In addition, increases the ductility of the whole structure more than pure concrete structure. In many researches, carried out composite structural regularities by using CFS and construction aspects as well, these kinds of structural systems were very efficient and economic than steel or reinforced concrete alone. Smith and Couchman [12] investigated the ductility and strength of headed stud shear connectors in the profiled steel sheeting. A series of push out test were performed on 27 samples by using a newly developed push rig. The experiment included various parameters such as mesh position, transverse spacing of shear connectors, number of shear connectors per trough, and the depth of the slab. They noticed that the mesh found at the nominal cover under the slab top and directly on the profile steel sheeting top resulted in higher ductility and strength (about 30%) of the shear connectors. Furthermore, transverse spacing of the shear connectors was found to have small effect on the shear resistance. However, the third shear connector has no effect rather than using the shear connectors in pairs. Also, Smith and Couchman found that increasing the slab depth is accompanied by increasing in the resistance of the shear connectors. Xu *et al.* [13], studied the static analysis of headed shear studs group with model push-out tests. Two groups of samples proposed by the authors called DT, and QT were designed and tested namely, DT1, DT2 and DT3 as well as QT1, QT2 and QT3. As result to studs group that has larger shank diameter (19mm and 22mm), their mechanical behavior had little effect from the biaxial action. Adding the initial bending-induced concrete cracks appeared unfavorable to the stud shear hardness. Xu and Sugiura [14] studied push-out analysis for a group of headed stud shear connectors under the effect of bending-induced concrete cracks. It was observed that the bending induced concrete cracks caused stud hardness reduction. It leads to the shear load transferred from the stud to the concrete during the pushed-out process to be unfavorably affected by the cracks. Bamaga and Tahir [15] studied innovative shear connectors for composite beams. They used a CFS section and profiled concrete slab with the suggested innovative shear connectors. The ductility and the strength capacities of the suggested shear connectors were investigated using push-out tests. The results of the suggested shear connectors showed strength capacities, large deformation and showed that they can be used for lightweight composite beams.

Lakkavalli and Liu [4] made an experimental study on composite cold- formed steel C-section floor joists. Twelve large-scale slab specimens accompanied with twenty-two push-out samples were tested to investigate the behavior and strength capacity of composite slab joists containing cold-formed steel C-sections and concrete. Four shear transfer mechanisms including surface bond, pre-fabricated bent-up tabs, pre-drilled holes, and self-driven screws were used on the surface of the flange embedded in the concrete to provide shear transfer ability. Results proved that the samples that were used with shear transfer enhancement showed a marked increase in strength and reduced deflection in comparison with those depending on a normal bond between steel and concrete to resist shear. Among the four shear transfer enhancements indicated the bent-up tabs provided the best action for both the strength and serviceability limit states, followed by drilled holes in the embedded flanges. In addition, the use of self-driven screws resulted in the lowest strength increase. Drilled holes were recommended to be industrially applicable due to its simplicity of fabrication, effectiveness and economy.

Irwan *et al.* [16] studied shear transfer enhancement in the precast cold-formed steel-concrete composite beams. Ten push-out specimens were tested in order to investigate the strength and behavior of bent-up taps shear transfer enhancement. The bent-up triangular tab shear transfer (BTTST) and angles bent-up tabs were studied in this research. As a result, the shear capacities of the samples employed with the shear transfer enhancement increased in comparison with those depending only on a normal bond between cold- formed steel and concrete. After comparing the shear transfer enhancements they have concluded that the BTTST provided a better action in terms of strength resistance as compared with the bent-up tab shear enhancement.

In this paper, a new technique of shear dowels for composite beams which consist of lipped channels cold formed steel beam and concrete slab. The innovative shear dowel (bent up half flange) is presented to connect the concrete slab and channel steel beam and to generate the composite action. The suggested shear dowel is easy to be fabricated.

3. The experimental Program

Four push-out test specimens were tested to study the behavior and capacity of the suggested shear dowel. The parameter studied in this research is the shape of the shear dowel.

3.1. Test Specimens

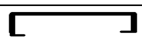
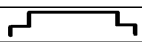
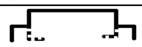
The experimental program consists of testing four push-out specimens (P1 through P4) under axial loading. The thickness of specimens was identical, 4 mm. These Specimens P1, P2, P3, and P4 were different in shear dowel shape as shown in table (1), figure (1) and figure (2). The first specimen (P1), is without shear dowel, (embedded in concrete with 2.5 cm) while the second specimen (P2) is with full bent up half flange with angle 45^o, the third specimen (P3) is with full bent up half flange and the last specimen (P4) with partial bent up half flange (every 10 cm) as shown in figure (3). The test parameter is the shape of the shear dowel as shown in table (1). CFS section beams are formed of two lipped channels which were used with the flanges cast into a 350 mm wide x 60 mm depth x 350 mm length concrete slab. One layer of 100 mm square welded wire steel reinforcements with diameter 5 mm was provided in the concrete slab. A recess of 50 mm in height was provided between the bottom of the concrete slab and lower end of the cold-formed steel section to allow for slip during testing. Each specimen has different shear dowel configuration as shown in figure (1) and figure (2).

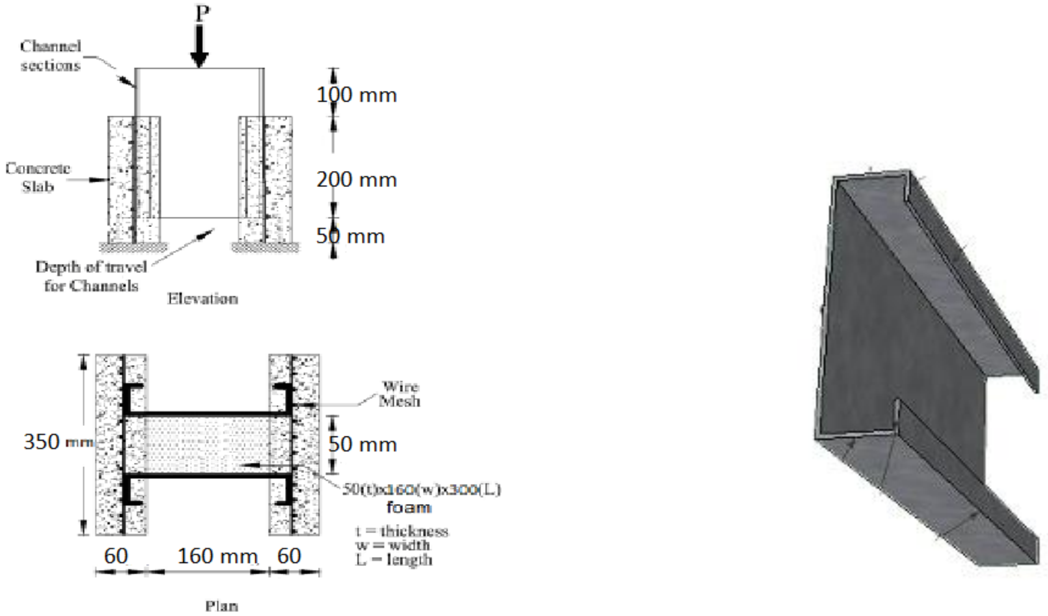
3.2. Test Setup and Procedure

Three LVDT displacement transducers were installed to measure the slip at the steel-to-concrete interface as in figure (4). Before each test, specimens were subjected to two cycles of loading using a nominal compressive load of 5% of the estimated ultimate load to ensure that the specimen and instrumentation were seated properly for testing. Testing was discontinued when the specimen failed to take additional load or when a significant load drop had occurred.

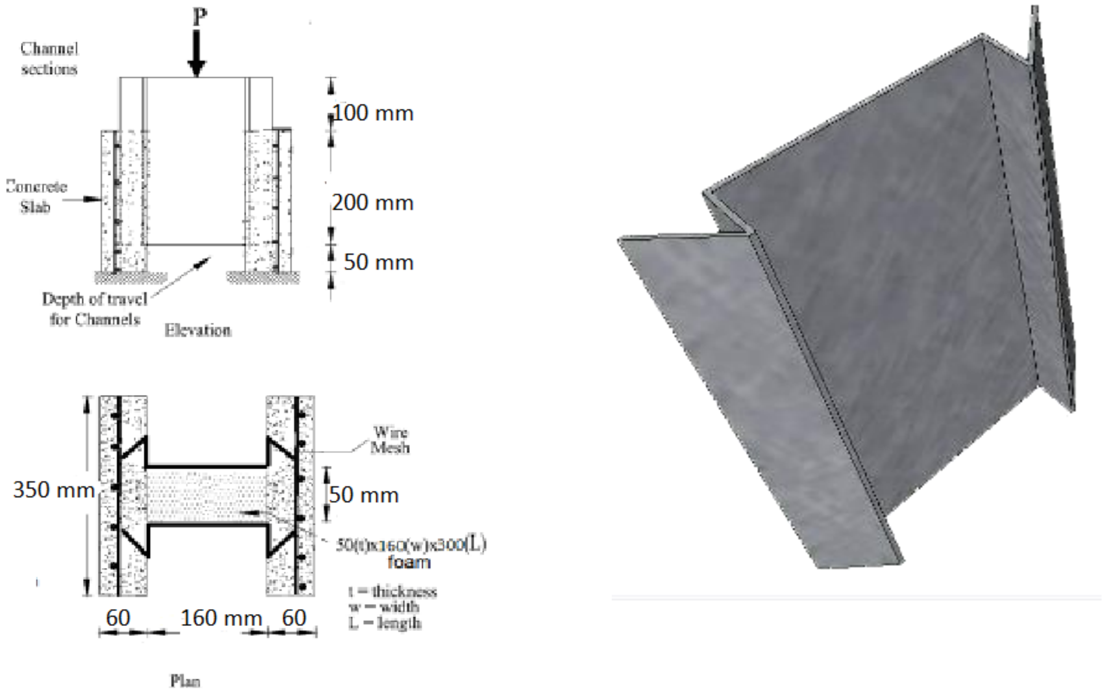
NB: T1, T3 (LVDT on each side of specimen) and T2 (LVDT on mid of specimen) (figure 6)

Table (1): Details of specimens for push out tests.

Specimen No.	slab thick-ness (mm)	Steel thick-ness (mm)	Shape of steel section	Description	Figure
P1	60	4		embedded in concrete with 2.5 cm	1a
P2				full bent of half flange with angle 45	1b
P3				full bent of half flange	2c
P4				partial bent of half flange (every 10 cm)	2d

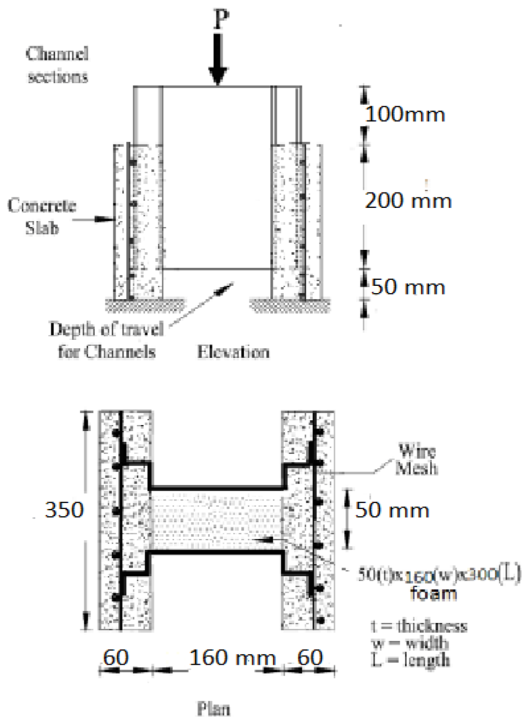


(a): Type P1



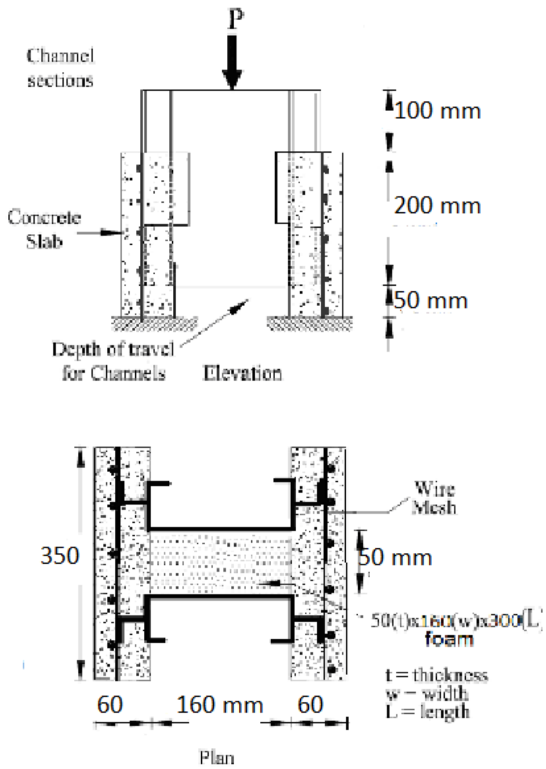
(b): Type P2

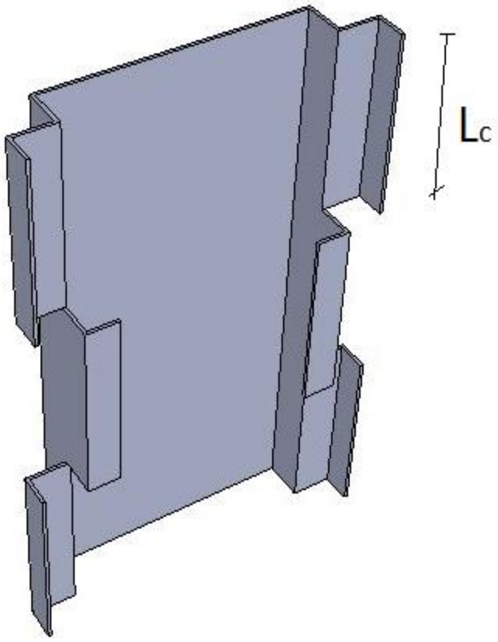
Figure (1): Push out test specimens (P1 and P2)



(C):

Type P3





(D):

Type P4

Figure (2): Push out test specimens (P3 and P4)

Figure (3): Partial bent up half flange for the channel (every 10 cm) (P4)

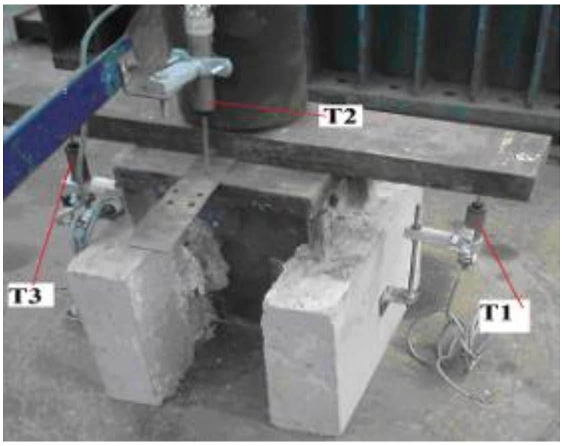


Figure (4): LVDT position on the specimens for push out test.

3.3 Material Properties of Specimens

3.3.1 Steel Bars and Steel Plates

Bars were diameter mild steel bars were used as main reinforcement for all beams. Tension tests were performed on three standard specimens; also a tension test was carried out on steel plate and Strain gauge was used to determine the actual stain and Young's modulus for each type. Table (2) gives the mechanical properties of the reinforcing used types and CFS steel plate.

3.3.2 Concrete

The gavel used in this work was local one having specific gravity and volume weight of 2.53 and 1.52 gm/cm^3, respectively and maximum nominal size of 20 mm. Sand from natural sources having a specific gravity 2.63, volume weight and fineness modulus of 1.73 gm/cm^3, 3.19, respectively, was used. Ordinary Portland cement was used in this study, the specific gravity 3.15, surface area 3200 cm^2/gm, initial setting time is 2.25hr and final setting time is 4.25 hr. The concrete mix was designed to have a 28 days cubic strength of about 27 N/mm^2. The concrete mix proportion is given in details in table (3). Longitudinal reinforcing steel and steel plate (CFS) was mild steel of grade 24/35.

Table (2): Mechanical properties of reinforcement steel.

Nominal diameter mm	Actual dia. mm	Yield stress (N/mm^2)		ultimate stress (N/mm^2)		Elongation%
		test result	ESS[#] 203/2008	test result	ESS 203/2008	test result
5	4.8	265	240	406	350	na
Steel plate	2[*]	272	240	381	350	28 %

(*) thickness of steel plate (CFS)

(#)ESS: Egyptian specifications

Table (3): Concrete mix proportion

Cement kg/m^3	Water L/m^3	Sand kg/m^3	Gravel kg/m^3
350	175	400	800

For each concrete batch, compressive strength, tensile strength and modulus of elasticity tests were performed on 15*15*15 cm cubes. The average compressive, tensile strength and modulus of elasticity were 27 N/mm^2, 3.12 N/mm^2 and 23.3 KN/mm^2, respectively.

4. Analysis of Push out Test

The purpose of push out test was to study the efficiency of bent up part of channel flange as shear dowel. The results that were sustained by testing of each specimen are summarized in Table (4).

4.1. Load-Slip Behavior, Ultimate Loads

The ultimate load, P_u for each push-out specimen is listed in Table (4). The slip measured varies from 3.48 mm to 5.97 mm as shown in table (4). All slip values are less than 6 mm as defined in EC4 [17]. Figures (5) to (11) show the typical load-slip curves for push-out specimens.

4.2 Failure Mechanisms

Description of observed failure mechanisms are presented besides the experimental results of push out tests. The failure mode observed in each push out test specimens can widely be divided into two types, as bonding failure or concrete crushing-splitting.

4.2.1 Failure Type 1: Bonding Failure

Tracing longitudinal cracks of concrete because of the downward slip of the cold-formed steel is the main feature of this failure mechanism. Specimens (P1, P2 and P3) showed that kind of failure mode as shown in figures (12), (13) and (14). The shear resistance is resisted by the bonding between concrete and cold-formed steel only. Failure of specimens (P1) (embedded in concrete slab), P2 and P3 rely on the bonding interface between the cold formed steel section and the concrete slab.

4.2.2 Failure Type 2: Concrete Crushing-Splitting

In the other specimen with shear dowel enhancement P4), failure started by concrete crushing followed by splitting of the concrete slabs as shown figure (15). This phenomenon refers to the shear dowel of the cold-formed steel section (P4) to some extent prevents the slip between concrete and cold-formed steel. It was observed that all specimens exhibited substantial inelastic deformation before failure. There was no evidence of sudden failure at ultimate load. With further deformation accompanied by increase in the load, failure was evident by concrete crushing. Figures (12) to figure (15) show typical cracking model in push-out test specimens. It was observed that most of the specimens had the same crack model. After reaching the maximum load, the bonding of interface between the CFS and concrete was lost.

Table (4): Experimental results of ultimate loads for push out tests**.**

Specimen No.	Slab thickNess (mm)	CFS thickNess (mm)	Ultimate load, P_u (kN)	Average slip at P_u, δ_u (mm)	Failure mode
P1	60	4	149.7	5.97	Bonding failure
P2			178.8	5.84	Concrete crushing-splitting
P3			170.6	3.48	
P4			280.3	4.02	

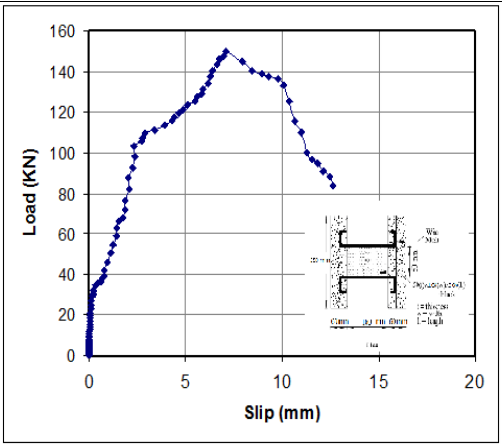


Figure (5): Load-slip curves for push-out specimen P1 (T2)

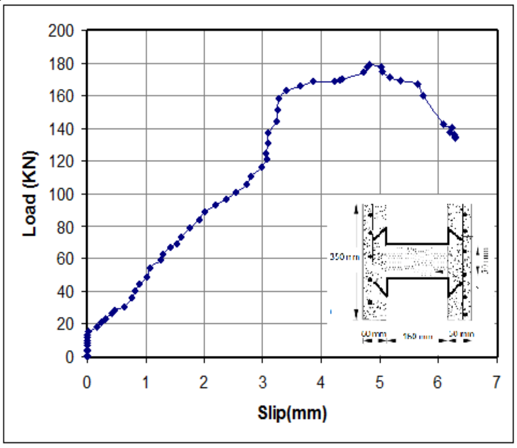


Figure (6): Load-slip curves for push-out specimen P2 (T2)

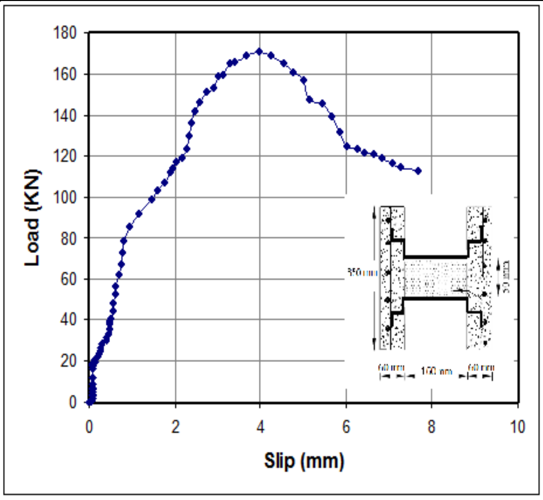


Figure (7): Load-slip curves for push-out specimen P3 (T2)

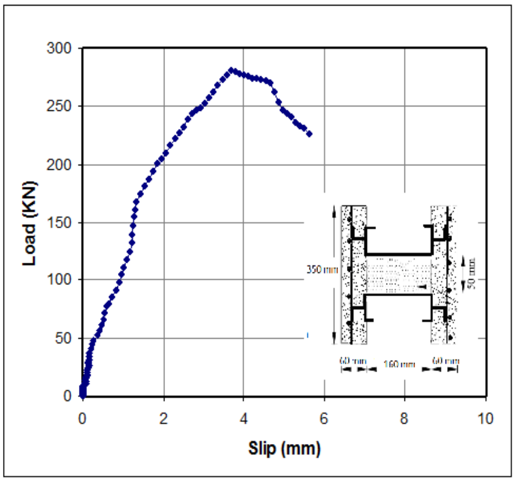
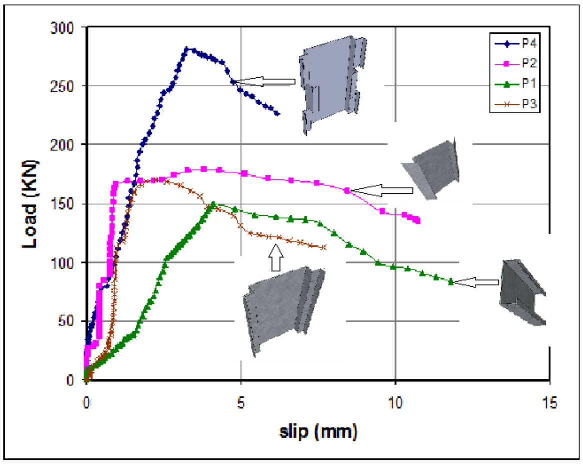


Figure (8): Load-slip curves for push-out specimen P4 (T2)



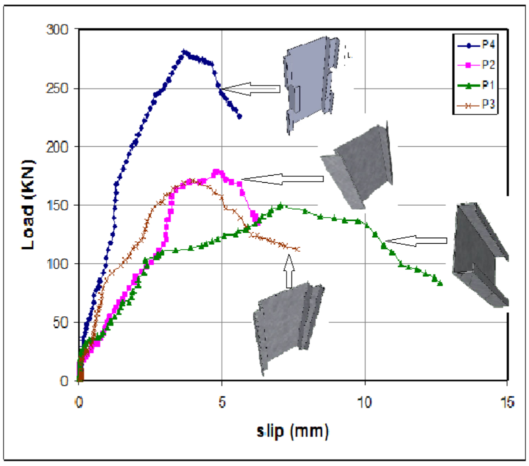


Figure (9): Load-slip curves for all push-out specimens (T1)

Figure (10): Load-slip curves for all push-out specimens (T2)

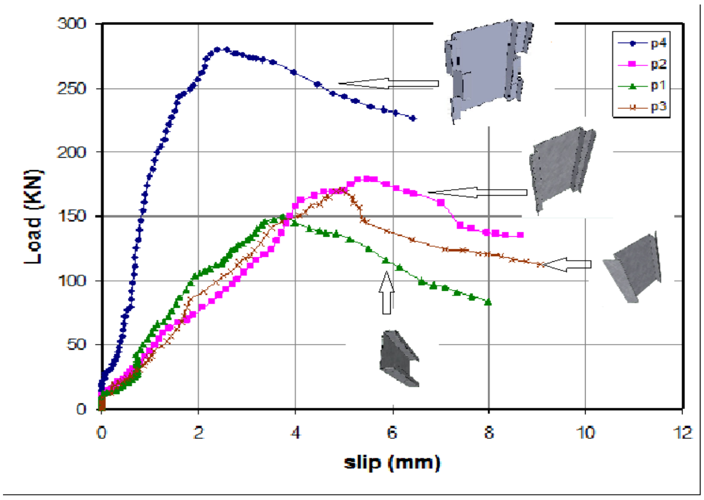


Figure (11): Load-slip curves for all push-out specimens (T3)

NB: T1,T3 (LVDT on each side of specimen) and T2 (LVDT on mid of specimen)

Figure (12): Failure of specimen (P1) without shear transfer enhancement.

Figure (13): Failure of push-out specimen (P2)

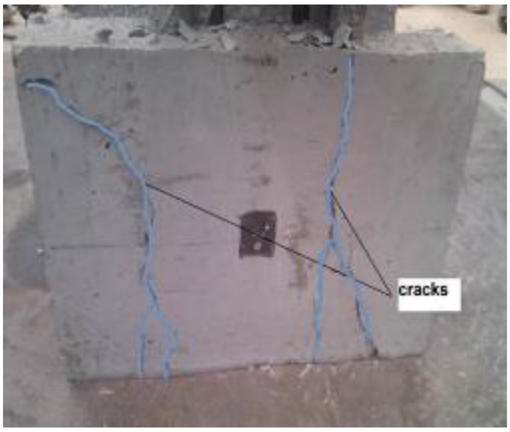


Figure (14): Typical cracking mode in push-out test specimen (P3).

Figure (15): Typical cracking mode in push-out test specimen (P4).

4.3 Effect of Shear Dowel Shape:

The shape of the shear dowel can affect the capacity and slip of composite beams. The Suggested shear dowel enhancement (bent up half flange) has a significant role in composite action. As shown in table (4) and figure (16), specimen (P1), without shear dowel, has an ultimate load of 149.7 kN, while specimen (P2), with full bent up half flange with angle 45^o, has an ultimate load of 178.8 kN. Specimen (P3), with full bent up half flange, has an ultimate load of 170.6 kN, while specimen (P4), with partial bent up half flange every 10 cm, has an ultimate load of 280.3 kN. These results lead to load capacities for specimens (P2, P3 and P4), with suggested shear dowel, higher than the first specimen P1 (embedded in concrete), which are increased by 14% to 87%. The ultimate capacity of specimens with partially bent up half flange (P4) is 61% and 64% higher than the specimens with full bent of flange (P2 and P3). Overall, the ultimate load for specimen (P4), with partially bent up half flange, is higher than specimens embedded in concrete (P1) or full bent up flange (P2 and P3).

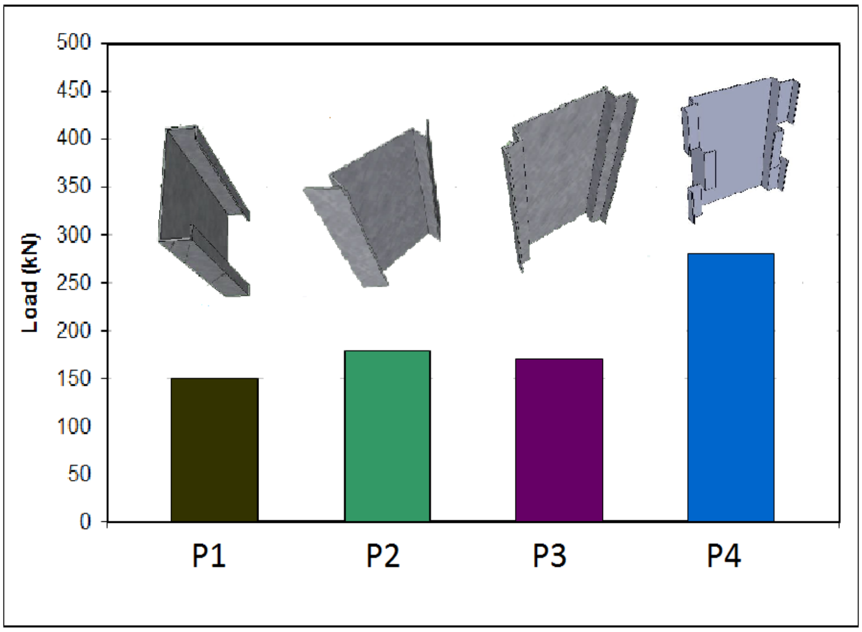


Figure (16): Bar chart for the ultimate load for the push out test**.**

5. Conclusions

Based on the results of four push-out specimens, the following can be concluded:

1- The failure modes observed in push-out test specimens can broadly be classified into two types, as bonding failure and concrete crushing.

2- Load capacities for specimens with the proposed shear dowel are relatively high as compared to control specimen (without shear dowel), which increased by 14% to 87%.

3- The partial bent up half flange has higher capacity than the full bent up half flange along the section.

4- The ultimate capacity of specimens with partial bent of flange is 61% and 64% higher than specimens with full bent up flange.

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