The effect of bent-up tab shear transfer enhancement shapes, angles and sizes in precast cold-formed steel-concrete composite beams

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Abstract

This paper deals with the evaluation of the effect of shapes, angles and sizes of bent-up tab shear transfer enhancement in precast cold-formed steel-concrete composite beams. The study is performed through push-out testing on 14 specimens. The push-out test has been employed to assess the shear strength as well as the behaviour of the shear transfer enhancement. It is shown that specimens employed with shear transfer enhancements increase the shear capacities of the specimens as compared to those relying only on a natural bond between cold-formed steel and concrete. In the shear transfer enhancements investigated, a new proposed shear transfer enhancement called bent-up triangular tab shear transfer (BTTST) provided the best performance in terms of strength. Shear capacities of the shear transfer enhancement also increase when the angles and sizes of bent-up tabs shear transfer enhancement is increased. It is concluded that more efficient and feasible precast cold-formed steel-concrete composite beams can be obtained with this innovator proposed shear transfer enhancement.
Keywords: cold-formed steel, composite beams, precast beams, shear transfer mechanisms.

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1 Introduction

The application of cold-formed steel composite concrete floor systems in small commercial and residential construction has gained popularity in recent years. The application of this system only uses cold-formed steel sheets. However, the use of cold-formed steel sections, such as C-section, as the composite floor joint in slab systems is still limited. The structural performance of cold-formed steel can be improved by using it in conjunction with other materials, such as concrete, to form the composite system. Common ways to do this are to use the cold-formed sections as composite beams in concrete slab systems [1]. However, a previous study showed that there is very little work and a lack of technical literature, such as codes of practice, regarding cold-formed steel-concrete composite beams [2]. The main problem for cold-formed steel-concrete composite beams is the welding of shear studs, due to the light gage and thickness of the sections for cold-formed steel being too small. From this viewpoint, this research is being carried out to study the possibility and performance of the use of back-to-back cold-formed steel lipped channels by bolted connection to form the I-beam. The top flange of the I-beam was modified by providing the new proposed shear transfer enhancement, named bent-up triangular tabs shear transfer (BTTST) to be used in the composite concrete floor systems. The purpose of this research was to investigate experimentally the efficiency of the BTTST in push-out testing and to determine the strength and behaviour of the shear transfer enhancement. Fourteen push-out specimens were constructed and tested to assist with evaluation.

2 Parametric study

Three parameters were identified as being of particular importance, as they affect the strength capacity of the shear transfer enhancement. These parameters are as follows.

2.1 Shapes of shear transfer enhancement

Two shapes of shear transfer enhancement were tested.
(i) Lakkavalli and Liu bent-up (LYLB) as shown in Figure 1 [3].

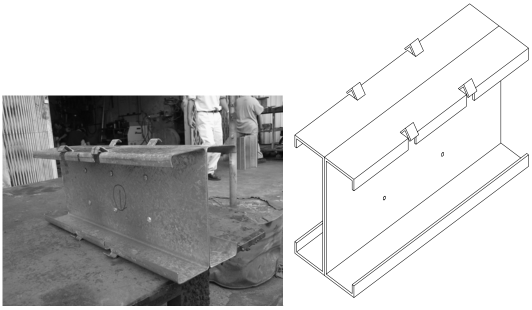

Figure 1: Lakkavalli and Liu bent-up tabs shear transfer (LYLB).

(ii) A newly proposed shape, named the bent-up triangular tab shear transfer (BTTST) as shown in Figure 2.

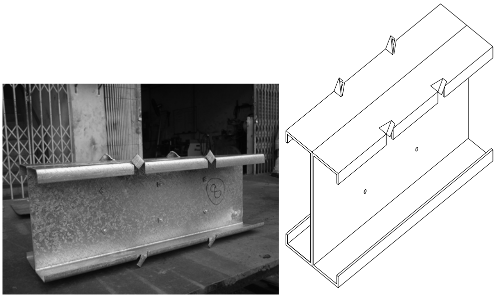

Figure 2: Bent-up triangular tab shear transfer (BTTST).

2.2 Angles of shear transfer enhancement

Three different angles θ were studied (Figure 3), i.e. 30°, 45° and 60°.

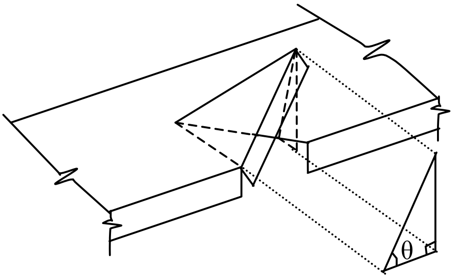

Figure 3: Angles, θ of the shear transfer enhancement.

2.3 Sizes of shear transfer enhancement

The dimensions of the tabs, (A x B) (Figure 4) are 20mm x 20mm, 25mm x 25mm and 30mm x 30mm.

3 Experimental program

3.1 Specimen

In this study, 14 push-out test specimens were tested to failure. Figure 5 shows the detail of the cross section of the push-out test specimen. A cold-formed steel I-section beam formed by a back-to-back lipped channel was used with the flanges cast into a 300mm wide x 90mm depth x 550mm height concrete slab. One layer of 100 mm square welded wire fabric steel reinforcements with a diameter of 8 mm was provided in the concrete slab. A recess of 50mm in height was provided

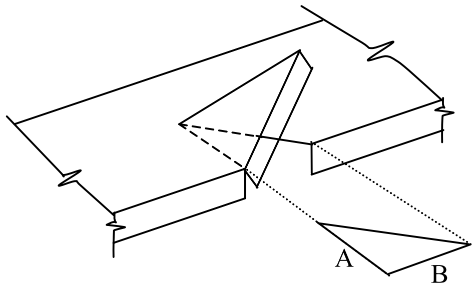

Figure 4: Calculated area (A x B) of the shear transfer enhancement.

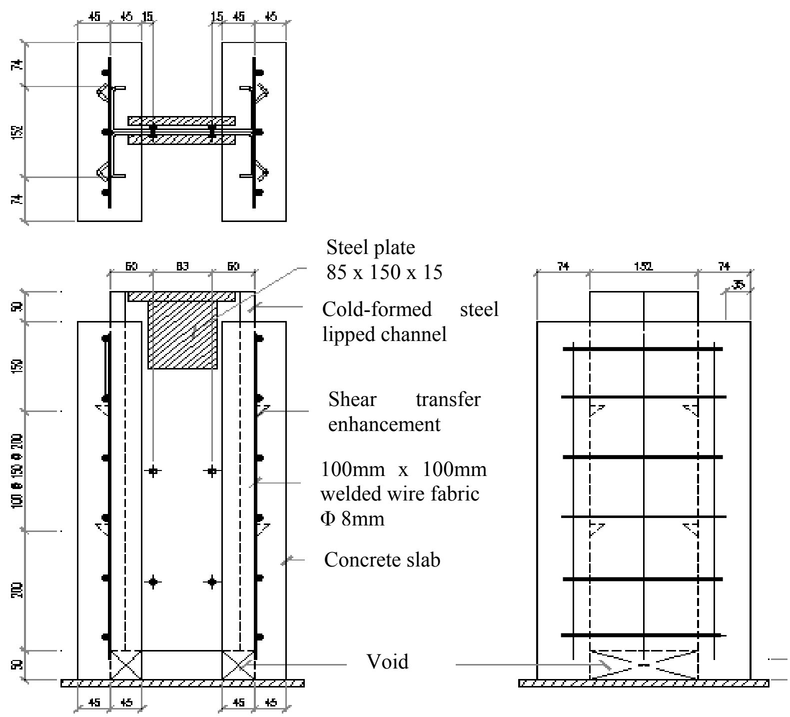

Figure 5: Layout for the push-out test specimen.

between the bottom of the concrete slab and the lower end of the cold-formed steel section to allow for slip during testing. Twelve specimens were provided with the shear transfer enhancement connectors in the spacing of 150 mm on the steel flange as shown in the figure. Meanwhile, two out of the fourteen specimens (S1 and S10) without the shear connector are used as the control

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specimens. Both sides of the flange of the I-beam for each specimen were embedded in the concrete slab to form the composite system. The details of each specimen are summarized in Table 1.

Table 1: Specimen push-out test.

No	Shape of Enhancement	Dimension of Enhancement (mm x mm)	Angle of Enhancement (degree)	Channel Section Thickness (mm)	Concrete Strength (N/mm^2)
S1	Without shear transfer enhancement (control)	-	-	1.9	36.62
S2	LYLB	25 x 25	45	1.9	36.62
S3	BTTST	25 x 25	45	1.9	36.62
S4	BTTST	25 x 25	30	1.9	36.62
S5	BTTST	25 x 25	60	1.9	36.62
S6	BTTST	20 x 20	45	1.9	36.62
S7	BTTST	30 x30	45	1.9	36.62
S8	Without enhancement (control)	-	-	2.4	36.62
S9	LYLB	25 x 25	45	2.4	36.62
S10	BTTST	25 x 25	45	2.4	36.62
S11	BTTST	25 x 25	30	2.4	36.62
S12	BTTST	25 x 25	60	2.4	36.62
S13	BTTST	20 x 20	45	2.4	36.62
S14	BTTST	30 x30	45	2.4	36.62

3.2 Test setup and procedures

As shown in Figure 6, the specimen was placed vertically in the Universal Testing Machine (UTM IPC 1000). It was loaded by the 1000kN existing jack vertical load through a displacement-controlled method and monitored by the readings from calibrated load cells. The control speed of the displacement was set at 0.0095 mm/s. The test procedure was based on Eurocode 4 [4]. The load was applied up to 40% of the estimated failure load. The load will be cycled 25 times between 5% and 40% of the expected failure load. Testing was discontinued when the specimen failed to take the additional load or when a

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significant load drop had occurred. After the test, the specimen was dismantled to investigate the condition of the shear transfer enhancement wherever possible. The vertical slips between the slab and the cold-formed steel beam were measured by two displacement transducers (LVDT). Transducers were placed vertically at both sides of the cold-formed steel web specimen. Thin plywood with 3mm thickness was placed beneath the slab and on to the upper part of the beam to level the surface. Steel plate of 30mm thickness was placed on the upper plywood to receive the jack. Steel plates were fastened to the loaded end of the cold-formed steel to prevent local buckling.

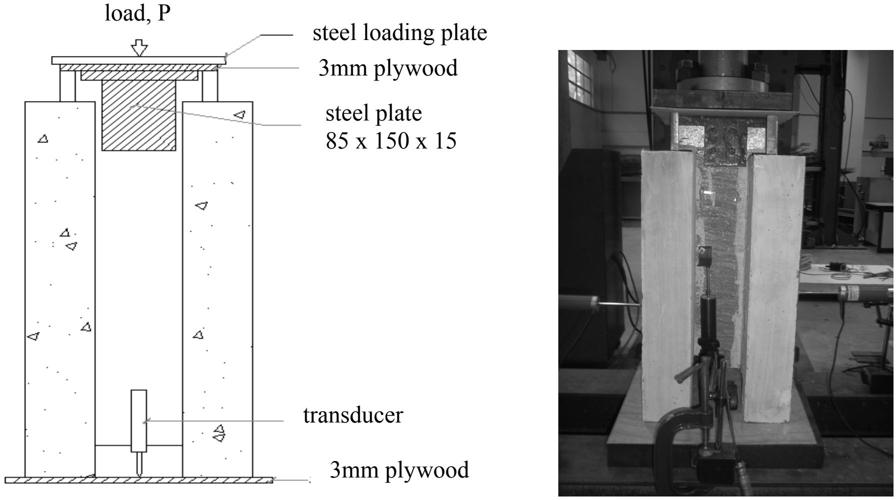


Figure 6: Push-out test arrangement.

4 Test results and discussions

Table 2 contains a summary of the test results at failure condition. More detailed observations of the mechanical behaviour of the tested specimens are presented in the following sections.

4.1 Effect of the shape of shear transfer enhancements

There will be two types of shear transfer enhancement discussed in this section named LYLB and BTTST in comparison with control specimen which no shear enhancement used and its covers both thickness of 1.9mm and 2.4mm. The test results indicate that a significant increment of loading achieved when bent-up tap shear enhancement used in both LYLB and BTTST for both thickness 1.9mm and 2.4mm. Referring to Figure 7, for 1.9mm thick cold-formed steel section, the loading increased more than 100% for BTTST and up to 80% for LYTB as compared to the control specimens, and for 2.4mm thickness, the result shows

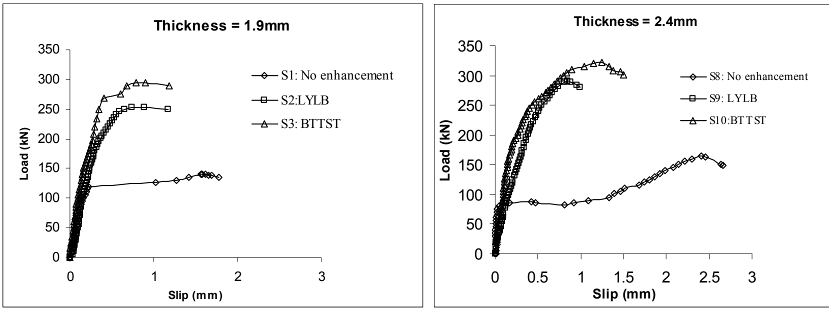
Table 2: Result of push test.

Sp.	Ultimate Load, $P_{u(\text{push})}$ (kN)	Percentage of P_u Compared with Specimen (100%)- (%)						Slip, δ_{push} (mm)
		Shape		Angle		Size		
S1	140.55	100	-	-	-	-	-	1.58
S2	253.19	180	100	-	-	-	-	0.88
S3	294.65	210	116	124	100	156.7	100	0.91
S4	237.50	-	-	100	-	-	-	2.22
S5	302.41	-	-	127.3	102.6	-	-	0.47
S6	188.05	-	-	-	-	100	-	0.62
S7	307.79	-	-	-	-	163.7	104.5	0.57
S8	163.81	100	-	-	-	-	-	2.40
S9	289.72	175	100	-	-	-	-	0.95
S10	321.14	196	112	108	100	136.7	100	1.25
S11	297.24	-	-	100	-	-	-	2.00
S12	352.00	-	-	118.4	109.6	-	-	2.56
S13	234.90	-	-	-	-	100	-	0.99
S14	358.35	-	-	-	-	152.5	111.6	1.31

the enhancement for LYLB and BTTST is increased up to 75% and 96% respectively. A comparison of the capacities of LYLB and BTTST indicates that the BTTST result in even higher capacities. The ultimate capacity of specimen S3 is 16% higher than that of specimen S2 and specimen S8, 12% higher than that of specimen S7. Figure 7 also shows that the specimens with shear enhancements demonstrate significantly reduced in term of slip at the interface as compared to the control specimen. Comparing between BTTST and LYLB, better performance demonstrates at ultimate load for both thicknesses by BTTST reflecting the effect plays by the concrete at upper part and lower part of the bent-up shear tab. These comparably more desirable results can be attributed to better interlocking at the cold-formed steel-to-concrete interface.

4.2 Effect of different BTTST angles

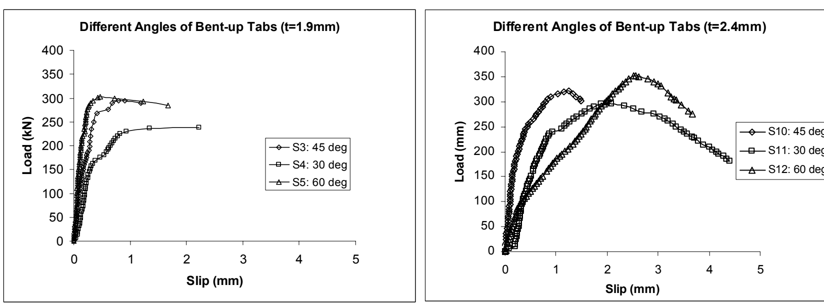
The other parameter which controls the capacity of the ultimate load is the angle of the bent-up tab. Referring to Table 2, with the same angle of bent-up tab, the ultimate loading capacity of the tested specimens with 2.4mm thickness is higher as compared with the specimens with 1.9mm thick. Its shows that the thicker the specimen there will be an increment in the stiffness hence increased the capacity of the ultimate loading. Referring to the specimens of 60^{o} for both thicknesses, the specimen S12 gives the 16% higher compared to the specimen S5 but more significant result shows by the specimen S11 as compared to the specimen S4



(a) 1.9mm thick cold-formed steel section

(b) 2.4mm thick cold-formed steel section

Figure 7: Shear transfer enhancement comparison load-slip curves.



(a) 1.9mm thick cold-formed steel section

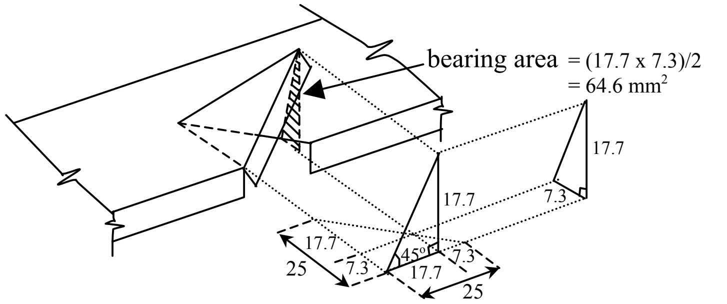
(b) 2.4mm thick cold-formed steel section

Figure 8: Effect of the BTTST of different angles on load-slip curves.

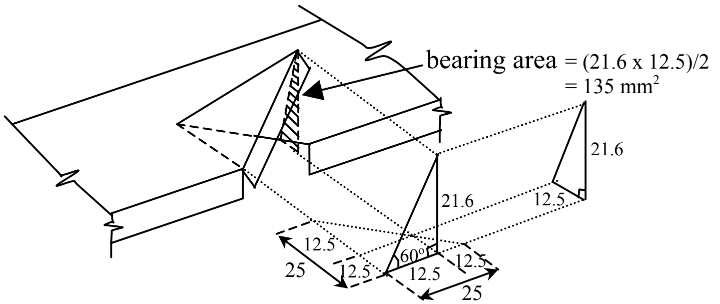
approximately 25%. Figure 8 shows the curves of the variation of ultimate load resulted from this parameter. The ultimate capacity of specimen S5 with angle 60° BTTST is higher than that of specimen S3 and S4 with angle 45° and 30°, respectively. It is 2.6% higher than specimen S3 and 27.3% than specimen S4. The ultimate capacity of specimen S3 is 24% higher than specimen S4. While from Figure 8(b), S12 with angle 60° BTTST shows a 9.6% increase in ultimate capacity over specimen S10 and 18.4% increase over specimen S11. Specimen S10 is higher by about 8% than specimen S11. By increase the angle of the bent-up tab, the bearing area of the tab will be increased hence the ultimate load of the push out test increased. Figure 9 shows the orientation of the tab with different bent-up tab angle. For angle 45° the bearing area measured was 64.6mm^2 and for angle of 60° the bearing area measured was 135mm^2 increased by up to 100%.

4.3 Effect of different BTTST sizes

Size of bent-up tab other than angle, also plays the important role to increase the bearing area hence the shear capacity of the tab. This study has been conducted

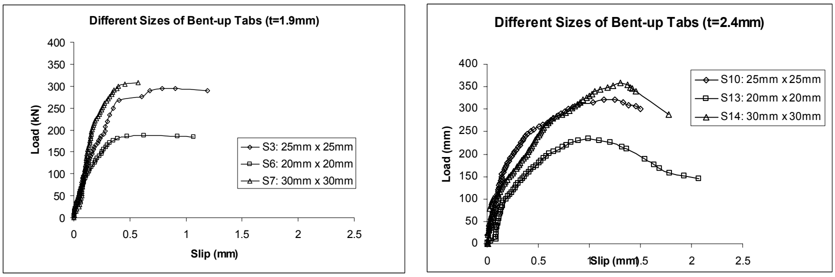


(a) Bearing area of BTTST with 45° angle



(b) Bearing area of BTTST with 60° angle

Figure 9: Bearing area of the BTTST.



(a) 1.9mm thick cold-formed steel section

(b) 2.4mm thick cold-formed steel section

Figure 10: Effects of different sizes of BTTST on load-slip curves.

on different sizes of bent-up tab shows the significant increment of the ultimate load with the increment of the bent-up tab size. For three sizes, which are 20mmx20mm, 25mmx25mm and 30mmx30mm for both thickness of 1.9mm and 2.4mm, all specimens demonstrated the variation on their ultimate load. Referring to Figure 10, the higher area of a bent-up tab gives the higher the ultimate capacity of the specimen. Specimen S7 and S14, 30mmx30mm tab area increase in ultimate loading significantly as compared to the specimen S3 and S10 with the 25mmx25mm tab area and S6 and S13 with the 20mm x20mm tab area. Referring to Table 2, specimen S14 (2.4mm thick) has an increment of 16% as compared with the specimen S7 (1.9mm thick) with the same shear area shows that the ultimate load was increased by increasing the thickness of the specimen. The same behaviour also showed by other tested specimens with different thicknesses. Figure 10 shows the increment of P_u when the size of BTTST is increased. Increased size of BTTST would increase the bearing area. As previously discussed, the increased of bearing area tends to increase the shear resistance. This can increase the load capacity on to the cold-formed steel until the concrete achieves the ultimate load and then cracks.

5 Conclusions

In this paper, the problems for cold-formed steel-concrete composite beam are discussed and the enabling solution for overcome the problem are described. Previous study showed that there is very little work and lack of technical literature such as codes of practice in cold-formed steel-concrete composite beams. From this viewpoint, this research is to be carried out to study the possibility and performance of the use of a new shape of shear transfer enhancement called bent-up triangular tabs shear transfer enhancement (BTTST). BTTST enhancement was employed on the surface of the flange embedded in the concrete to provide shear transfer capacity. Fourteen companion push-out specimens were tested to evaluate the strength and behaviour of a bent-up taps shear transfer enhancement. The results show that specimens employed with shear transfer enhancements increase the shear capacities of the specimens as compared to those relying only on a natural bond between cold-formed steel and concrete. As these two types of shear transfer enhancements investigated, BTTST provided the best performance in terms of strength. Shear capacities of the shear transfer enhancement also increase when angles and sizes of bent-up tabs shear transfer enhancement is increase. It is concluded that the proposed shear transfer enhancement has sufficient strength and it is feasible.

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