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Interfacial shear strength of steel angle anchors welded to U-shaped steel section

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ABSTRACT

In response to demand for floor area efficiency in multi-story buildings, the Korean steel industry developed steel-concrete composite beams utilizing cold-formed steel (CFS) beams and steel angle shear connectors. In this study, the interfacial shear resistance behavior of the posed system was investigated through a series of push-out tests. Effects of shear connector spacing, orientation, and concrete compressive strength on interfacial shear strength were analyzed. To evaluate pure shear connector strength, available methods to exclude concrete shear contribution and relations with interfacial crack width were discussed. Based on the test observations, the current application of the angle shear connector design equation in AC495 was evaluated.

1. INTRODUCTION

As an available option for floor area efficiency in multi-story buildings, a novel composite beam configuration has been developed by Korean steel industries. The developed composite beam system is characterized by a U-shaped (i.e., hat-shaped) cold-formed steel (CFS) section, and steel angle shear connectors provide the composite action between the steel section and concrete slab.

Since the posed composite beam system has infilled concrete inside the U-section, the load transfer mechanism at the concrete-steel interface is differentiated from the conventional composite beams with a wide-flange (WF) section. For adequate shear connector design of the posed system, interfacial shear transfer mechanism and strength should be evaluated.

This study investigated the interfacial shear behavior of the posed system through a series of push-out tests. Test results were compared with the AC495 angle shear connector design equation (ICC-ES 2018), and the interfacial shear contribution by concrete was discussed.

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2. TEST PROGRAM

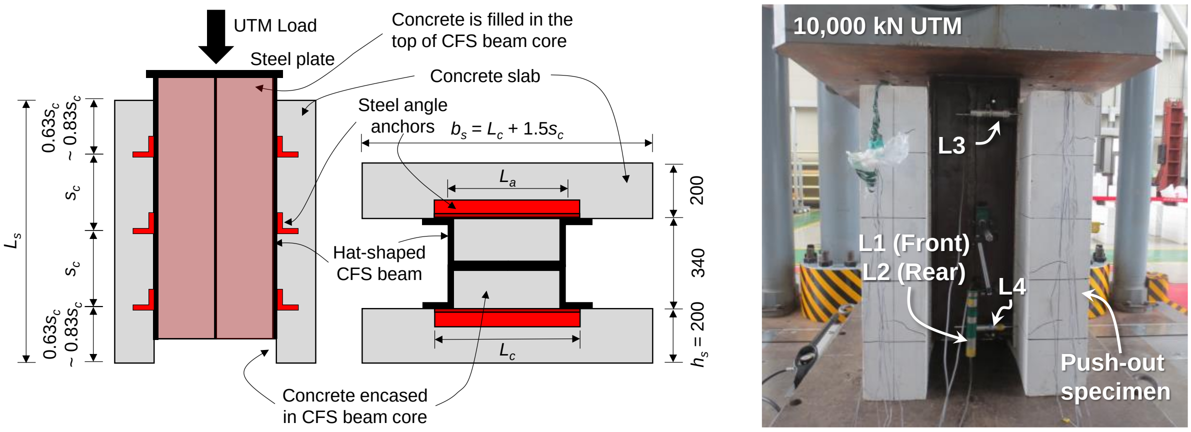
A series of push-out tests were performed on a total of 19 specimens. The authors' research article (Oh et al. 2022) provided detailed information on the push-out tests. Test parameters included shear connector orientation, spacing (s_c), and concrete compressive strength (f_c'). The design parameters of tested specimens are summarized in Table 1.

All tested specimens had a CFS beam-core with two U-sections welded back-to-back and two concrete slabs. Each concrete slab had a thickness of h_s = 200 mm, and varying width (b_s) and length (L_s) depending on shear connector spacing (s_c). Each U-section (i.e., U-400x400x170) had a thickness of t_s = 8 mm, height of h_{CFS} = 170 mm, and web-to-web clear distance of L_a = 384 mm. All equal-leg angle shear connectors had a height of h = 50 mm, web and flange thickness of t_w = t_f = 6 mm (i.e., L-50x50x6), and a length of L_c = 550 mm.

Table 1 Push-out test parameters and main results

Specimen Name	Test parameters			Test results		Calculation	
	Shear connectors		f_c' (MPa)	Q_{peak} (kN)	Δ_v (mm)	$Q_{n,AC495}$ (kN)	Q_{peak} / $Q_{n,AC495}$
	Orientation	s_c (mm)					
PT01-I175		175	20.8	624.5			3.39
PT01-I225	┘ └ (Inversed)	225	20.8	668.8	N.A.	184.3	3.63
PT01-I300		300	20.8	759.8			4.12
PT01-R175		175	20.8	685.0			3.72
PT01-R225	┐ ┌ (Right)	225	20.8	750.8	N.A.	184.3	4.07
PT01-R300		300	20.8	744.0			4.04
PT02-I175-1				502.3	6.38		2.74
PT02-I175-2		175	20.0	521.2	3.21	183.3	2.84
PT02-I175-3	┘ └ (Inversed)			469.5	4.30		2.56
PT02-I175-4				479.5	3.29		2.62
PT02-I400		400	20.0	699.3	4.08	183.3	3.81
PT02-I550		550	20.0	647.8	7.66		3.53
PT02-R400	┐ ┌ (Right)	400	21.4	844.5	4.13	188.0	4.49
PT02-R550		550	21.4	819.5	4.68		4.36
PT03-I175-1				622.6	1.90		2.27
PT03-I175-2				614.2	4.32		2.24
PT03-I175-3	┘ └ (Inversed)	175	35.4	664.1	2.69	274.2	2.42
PT03-I175-4				646.1	2.61		2.36
PT03-I175-5				639.0	2.80		2.33

Test protocol followed AC495 (ICC-ES 2018). A 10,000 kN universal testing machine (UTM) was used to apply monotonic loading under displacement control. Test load was applied at the top of CFS beam-core at a rate of 0.01 mm/sec. The test was terminated when the applied load decreased to 75% of the peak load (P_{peak}). Two linear variable displacement transducers (LVDTs) (i.e., L1 and L2 in Fig. 1b) were installed on both sides of CFS beam-core to measure horizontal slip between the CFS beam and concrete slab (Δ_h). Two additional LVDTs (i.e., L3 and L4 in Fig. 1b) were installed at the top and bottom of CFS beam-core, which recorded the interface separation between the steel beam and concrete slab (Δ_v). The push-out specimen details and test setup are described in Fig. 1.



(a) Push-out specimen details (b) Test setup

Fig. 1 Push-out specimen details and test setup

3. TEST RESULTS AND DISCUSSION

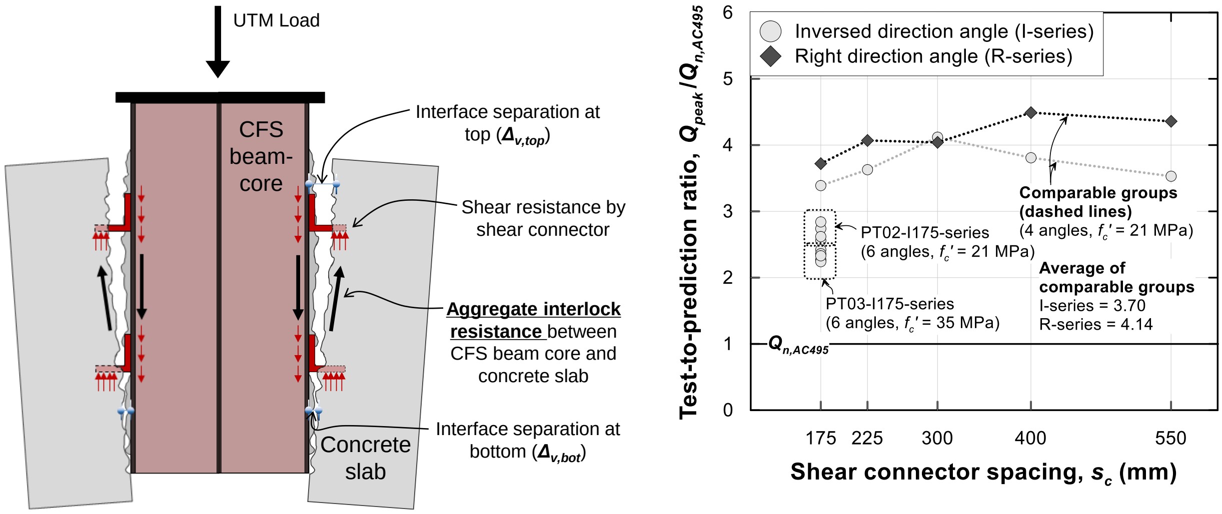
Push-out test results are summarized in Table 1. Generally, tested strength was proportional to shear connector spacing (s_c), attributed to the shear contribution of intact concrete at the interface. However, excessive interface separation (Δ_v) caused reduced aggregate interlock resistance (Fig. 2a) for wide shear connector spacing specimens (400 and 550-series).

The right direction angle specimens (R-series) showed greater push-out strength than the inversed angle specimens (I-series). The different concrete bearing stress distribution had been expected depending on the angle direction, but it could not be experimentally proved due to instrumentation limitations. The effects of angle orientation need to be further verified by an additional numerical investigation.

Fig. 2b shows the ratio of measured peak strength (Q_{peak}) to the predicted strength ($Q_{n,AC495}$) by AC495 design equation (Eq. 1). The design equation showed substantial conservatism, attributed to the concrete shear contribution. However, the measured strength was provided by intact concrete as well as shear connectors. Thus, the adequacy of Eq. (1) should be evaluated by excluding the concrete contribution.

$$Q_n = \frac{600\left(t_f + 0.5t_w\right)\sqrt{f_c' E_c}}{\sqrt{L_a}} \qquad (1)$$

Where Q_n is the nominal shear strength of a steel angle anchor (N), t_f and t_w are the flange and web thicknesses of steel angle anchor, respectively (mm), L_a is the web-to-web clear distance of U-shaped CFS beam (mm), f_c' is concrete compressive strength (MPa), and E_c is the modulus of elasticity of concrete (MPa).



(a) Aggregate interlock resistance at the concrete interface

(b) Ratio of measured-to-predicted interfacial shear strength ($Q_{peak}/Q_{n,AC495}$)

Fig. 2 Interfacial shear strength evaluation of angle shear connectors welded to U-shaped steel beam

4. CONCLUSIONS

This study investigated the interfacial shear strength of angle shear connectors welded to U-shaped CFS beams through a series of push-out tests. The currently available AC495 equation is highly conservative compared to the push-out test results, but the shear contribution of intact concrete needs to be excluded from the tested strength. The author's research article (Oh et al. 2022) provided more detailed discussions on the evaluation of concrete shear contribution and available design equations.

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