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Effect of shear connector shape and arrangement on shear strength of composite beams

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ABSTRACT

Recently, the application of composite beams to construction sites has been on the rise due to demands for skyscrapers, long-span structures, and story-height reduction and economic feasibility of buildings. Composite beams using Cold-Formed Steel (CFS) beams, concrete slabs, and shear connectors would have story-height reduction and construction period shortening effect. In this study, push-out test of concrete-CFS composite beams with shear connectors was conducted. The push-out test was performed on six specimens with the main variables of the interval, orientation and shape of shear connectors. The maximum strength, deformation, and strain of shear connectors were analyzed in accordance with AC495 (ICC-ES, 2018).

1. INTRODUCTION

Studies on composite beams have been conducted actively because the application of composite beams to construction sites has been on the rise due to its various advantages. In particular, use of composite beams using U-shaped Cold-Formed Steel (CFS) beams and shear connectors can lead to minimized story-height and reduced construction period, in comparison with conventional composite beams using wide flange sections and welded studs. In this study, shear strengths of composite beams using U-shaped CFS beams and angle/channel shear connectors were experimentally evaluated by conducting push-out tests and comparing with the values from several codes and guidelines for the design equations.

AC495 (ICC-ES, 2018) proposed the shear strength design equation of angle shear connectors welded to U-shaped CFS beam (Eq. 1), which is a somewhat similar form to the AISC 360 (AISC, 2016) design equation for channel shear connectors welded to wide flange section.

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$$Q_n = \frac{0.6(100\text{mm})^{3/2}(t_f + 0.5t_w)(f_{ck}E_c)^{1/2}}{\sqrt{l_a}} \quad (1)$$

where Q_n is strength of an angle shear connector (N), t_f is thickness of the upstanding leg of the angle (mm), t_w is thickness of the horizontal leg of the angle (mm), l_a is web-to-web clear distance of CFS beam (mm), f_{ck} is characteristic strength of concrete (N/mm^2), and E_c is elastic modulus of concrete (N/mm^2).

2. TEST AND MEASUREMENT METHOD

The push-out specimens were designed according to AC495 (ICC-ES, 2018). The interval, orientation and shape of shear connectors were considered as main variables of six specimens. The drawing of specimens and the measurement plan of strain gauges and linear variable displacement transducers (LVDT) are shown in Fig. 1. The specimen had four shear connectors attached to the U-shaped CFS beam (two shear connectors in each side). Ten strain gauges were attached to the lower shear connectors to measure deformation of shear connectors (five strain gauges on each side). Strain gauges were attached to one side (G1~5), oriented in the longitudinal direction, while the rest of them were attached on the other side (G6~10) in the transverse direction. LVDT1 and 2 were installed on the U-shaped CFS beam for measurement of horizontal slip between the U-shaped CFS beam and concrete slabs, and LVDT3 and 4 for measurement of gap between the U-shaped CFS beam and concrete slab.

The push-out tests were performed using a 10,000 kN universal testing machine (UTM) (Fig. 2). The UTM load was applied statically at a rate of 0.01 mm/sec under displacement control according to the AC495 (ICC-ES, 2018), Section 4.3.2. The UTM load was applied until the load decreased to 75% of peak load, and the load was measured by a load cell built into the UTM.

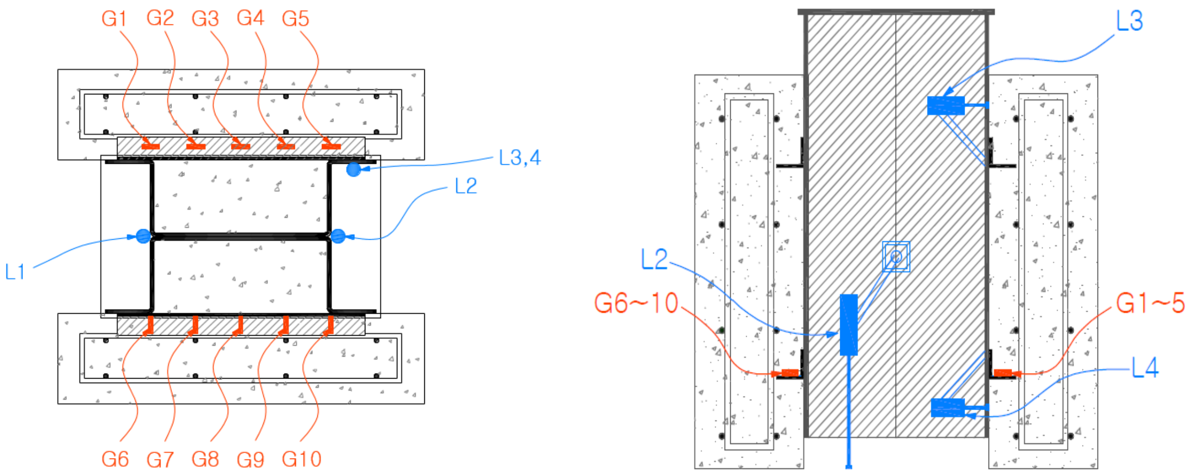

Fig. 1 Push-out specimen and measurement plan

Fig. 2 Push-out test set up with UTM

3. TEST RESULTS

Table 1 summarizes results of the push-out test. In all specimens, the measured maximum shear strength was 3 to 4 times higher than nominal shear strength calculated by Eq. (1). This indicates that the shear strength design equation of AC495 (ICC-ES, 2018) is significantly conservative. This equation may be in need of revision for more efficient design of shear connectors. Maximum shear strength of specimens of which interval of shear connectors was 400 mm was measured higher than 500 mm interval specimens. In terms of shear connector shape and orientation variable, larger maximum shear strength was measured in the order of the right direction channel, the right direction angle and the inverse direction angle.

Table 1 Push-out test results

Specimen	Shape of shear connector	Shear connector interval (mm)	Measured peak shear strength (kN)	Nominal shear strength (kN)	Maximum slip (mm)
PT-I400	┘ └ (Inverse)	400	2,804	754.6	13.6
PT-R400	┐ ┌ (Right)		3,385	754.6	14.7
PT-C400	⊓ ⊓ (Right)		4,004	796.5	18.2
PT-I550	┘ └ (Inverse)	550	2,596	754.6	18.1
PT-R550	┐ ┌ (Right)		3,287	754.6	12.3
PT-C550	⊓ ⊓ (Right)		3,512	796.5	14.8

Based on the results of strain gauges attached in the lateral direction (G1~5), most of strain gauges did not reach the yield strain of shear connectors. Whereas, most of strain gauges attached in the vertical direction (G6~10) reached the yield strain of shear connectors. The average strain of G6~10 was measured higher than the average strain of G1~5, which means that in-plane bending deformation was dominant in shear connectors.

Regarding the measurement results of the gap between the U-shaped CFS beam and concrete slab, the gap remained almost constant in the elastic behavior region, while the gap increased rapidly in the inelastic behavior region. For all specimens, the horizontal slip between the U-shaped CFS beam and concrete slab was around 4 mm at the moment when the gap began to increase rapidly. The gap increased more rapidly in the specimens with angles than the specimens with channels.

3. CONCLUSIONS

In this study, effects of shear connector shape and arrangement on the shear strength of composite beams were analyzed by conducting push-out tests. As a result, the following conclusions were obtained:

(1) For all specimens, the measured maximum shear strength was 3 to 4 times the nominal shear strength calculated based on AC495 (ICC-ES, 2018). For design efficiency, the shear strength design equation proposed by AC495 (ICC-ES, 2018) should be reconsidered.

(2) The maximum shear strength was measured higher in the specimens with narrower interval of shear connectors. Also, the larger maximum shear strength was measured in the order of the right direction channel, the right direction angle and the inverse direction angle.

(3) The average strain were higher from the strain gauges attached in the transverse direction. This result indicates that in-plane bending deformation is dominant in shear connectors.

(4) Regarding the measurement results of the gap between the U-shaped CFS beam and concrete slab, the gap increased rapidly after reaching the nonlinear behavior region. In the specimens with angles, the gap increased more rapidly than the specimens with channels.

REFERENCES

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