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Shear strength of PC-CIP composite beams with Fixed Ends

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ABSTRACT

The use of composite members using precast concrete(PC) and cast-in-place(CIP) concrete with different compressive strengths has been increased. However, current design codes do not clearly provide the shear strength of the composite members with different concrete strength. In this study, the shear strength of PC-CIP composite beams with different concrete strength (24 MPa and 60 MPa) was experimentally evaluated. The test variables included the area ratio of two different strength concrete and support conditions. Test results showed that support conditions affect failure mode of RC beams and shear strength of PC-CIP composite beams increases in proportion to the area ratio of high strength concrete 60 MPa.

1. INTRODUCTION

Recently, the use of composite construction methods using precast concrete (PC) and cast-in-place(CIP) concrete has been increased to improve structural performance, workability, and economy. However, the current structural design codes do not clearly provide the method for calculating shear strength of such composite members. Kim et al. (2016, 2017, 2018, 2019) performed shear tests of composite beams using PC and CIP with different concrete compressive strength. According to test results of reinforced concrete composite beams, the depth and the concrete strength of the compression zone affected the shear strength of the composite beams (Kim et al. 2016, 2017). In the prestressed PC and CIP composite beam, the prestressed PC section increased the initial stiffness and shear strength of the beams (Kim et al. 2018, 2019). In the composite beams with steel fibers, the steel fibers resisted the opening of diagonal cracks, thus increasing the shear strength.

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However, previous studies for RC composite beams focused on vertical shear strength of simply supported beams; however, actual structural members of buildings are continuous or supported by fixed ends. In a flexural member with fixed ends, shear force diagram and bending moment diagram are different from those of a simply supported beam. Thus, shear strength of RC composite beams should be evaluated considering different support conditions. Particularly, for composite RC sections with different concrete strength, compressive zone is formed in the upper concrete at the center (by positive moment), while the compressive zone is formed in the lower concrete at both ends (by negative moment). In this study, therefore, shear strength of RC composite beams with fixed ends is experimentally evaluated.

2. TEST PLAN

2.1 Test Variables

In order to evaluate shear strength of RC composite beams with different concrete strength, four RC beams are tested. The major test variable is cross-sectional area ratio of high-strength concrete 60 MPa for PC and low-strength concrete 24 MPa for CIP concrete.

As shown in Fig. 1, four sections were considered: Monolithic sections A and B have 24 MPa and 60 MPa concretes in whole sections, respectively. Composite section C has 24 MPa concrete on the upper 3/8 section and 60 MPa concrete on the rest of section. Composite section D has 24 MPa concrete on the upper 5/8 section and 60 MPa concrete on the rest of section.

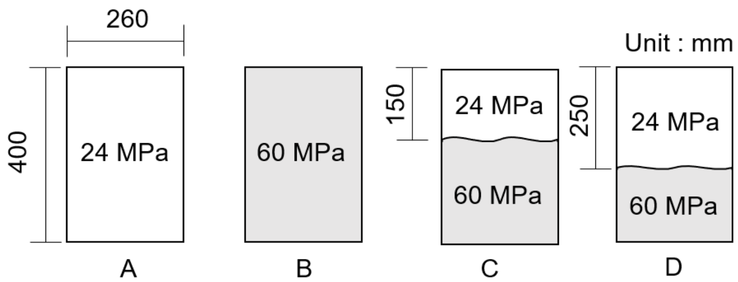
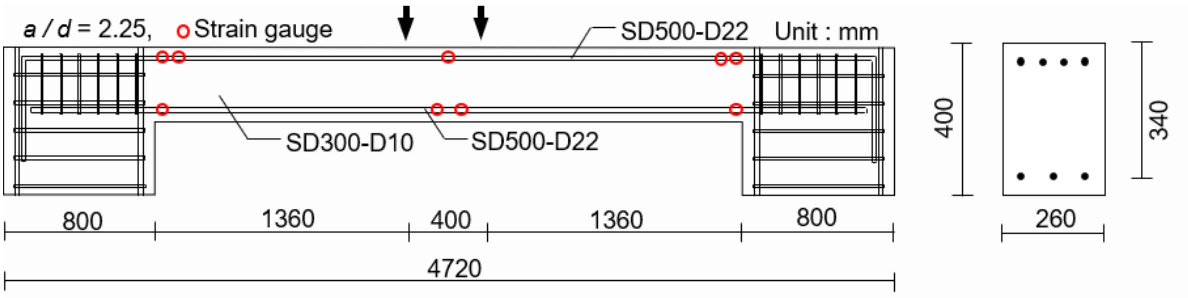


Fig. 1 Cross-section A~D

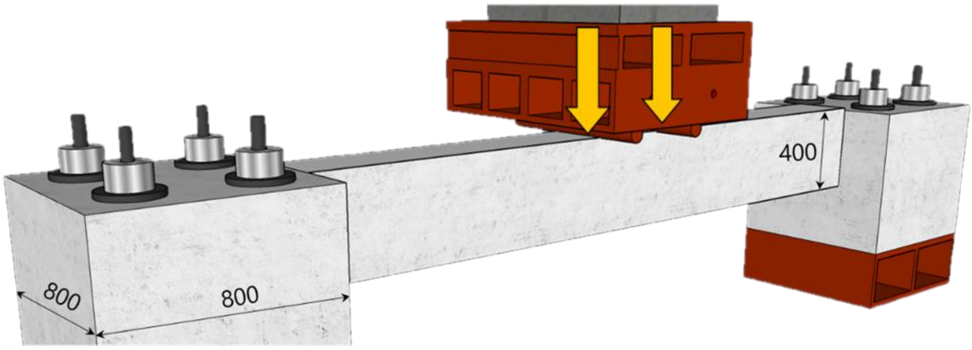
2.2 Specimen details

Reinforcement details used in specimens are shown in Fig. 2. The cross-section of the specimens is 260 mm x 400 mm. The distance from loading point to support is 1360 mm. Shear span-to-depth ratio a/d is 2.25 where shear span a is 765 mm from the maximum moment M_{max} to M = 0, and effective depth d is 340 mm.

For longitudinal reinforcing bars, 4-D22 and 3-D22 bars are used at the top and bottom of the sections, respectively. As shown in Fig. 2(b), for the fixed end condition at both ends, two columns with 800 mm x 800 mm were fixed to the strong floor by each of four steel bars. LVDTs were installed to measure the displacement at both ends and the center.



(a) Specimens F-A ~ F-D



(b) 3D modeling of test setup

Fig. 2 Rebar arrangement of specimens and test setup

3. TEST RESULT

3.1 Material strength

The mechanical properties of the SD500 D22 reinforcing bar used in the specimens were evaluated according to KS B 0801 and KS B 0802. The average yield strength f_y and yield strain ε_y of SD500 bar were 555 MPa and 2968 $\mu\varepsilon$, respectively (E_s = 187 GPa).

In this study, 24 MPa and 60 MPa concrete were used, and the maximum size of the coarse aggregate was 25 mm. The compressive strengths of concrete specimens with 100 mm x 200 mm were 21 MPa and 40 MPa, respectively.

3.2 Load and displacement relations

The load and center displacement relationship and final failure modes are presented in Fig. 3 and Fig. 4, respectively. Generally, the peak shear strength of RC beams without shear reinforcement are defined as the first point where the load was sharply dropped by the brittle diagonal shear cracking. The shear strength of section B with 60 MPa was the largest, followed by the lowest shear strength of sections A, D, C. Shear strength increased proportionally with cross-sectional area ratio of PC. Based on the current structural design code (KDS14 20 22), the shear strength ratio (V_{test}/V_{pred}) when calculating the predicted strength with effective concrete strength f_{cke} calculated from the cross-sectional area ratio was 1.83 to 1.87.

As shown in the failure pattern of the specimens (Fig. 4), the initial flexural cracks occurred at the bottom of the loading point and other flexural cracks developed at the top of both ends due to fixed end conditions. After the flexural cracks propagated to neutral axis, sections A, C, and D with 24 MPa in upper zone showed the maximum shear strength with splitting cracks along upper longitudinal rebars at both ends. Finally, diagonal shear cracking occurred. On the other hand, section B with 60 MPa showed maximum shear strength with splitting cracks along lower longitudinal rebars and diagonal shear cracks.

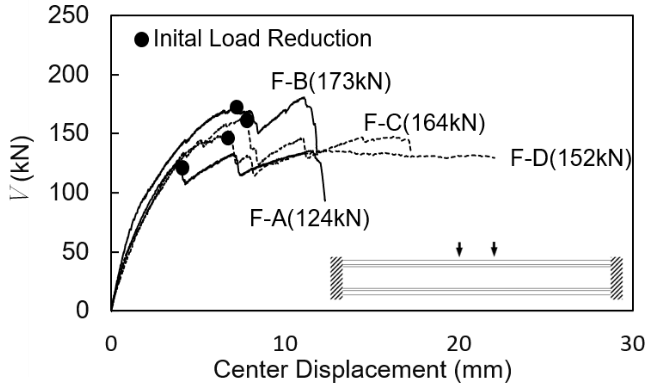


Fig. 3 Load-displacement relationship

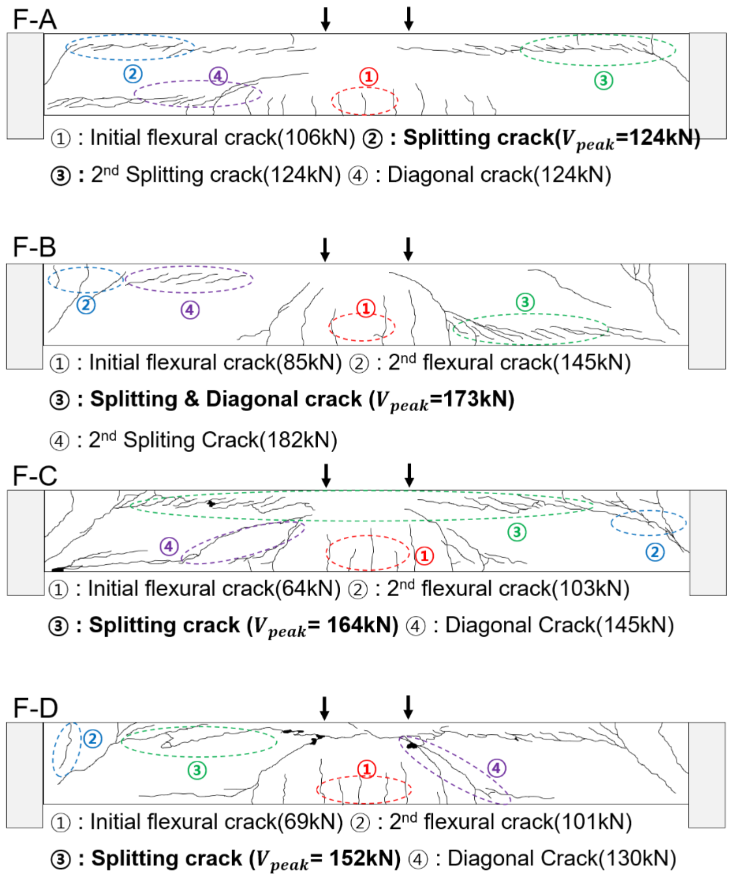


Fig. 4 Crack patterns of specimens at the end of tests

3.3 Comparison with current design code

The current design code (KDS 14 20 66) recommended that the shear strength of concrete composite sections should be predicted as follows. 1) Summing the shear strength of the individual cross sections of PC and CIP. 2) Calculating the effective concrete strength by the area ratio for the entire cross section. 3) To use only minimum concrete strength between PC and CIP.

Figure 5 shows shear strength prediction with the three different predictions by the current design code. The horizontal and vertical axes indicate the section type and the shear strength ratio (V_{test} / V_{pred}), respectively. The method of minimum strength showed the most conservative prediction. The effective concrete strength and simply summing method showed similar predictions. Although three methods predicted the test results on the safe side, the average strength ratio was 1.85 to 1.96, which was largely conservative. This indicates that the additional compression zone at both ends affects shear strength of fixed end beams as shown in Fig. 6. Further study should be needed to evaluate the effect of support conditions.

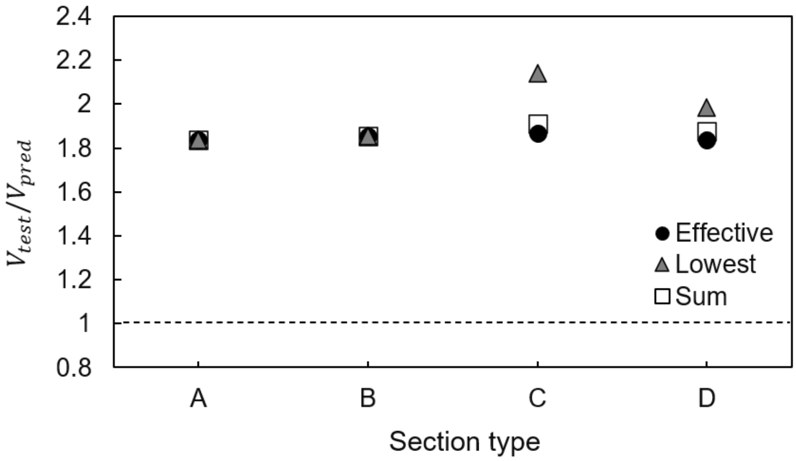


Fig. 5 Shear strength prediction by current design code

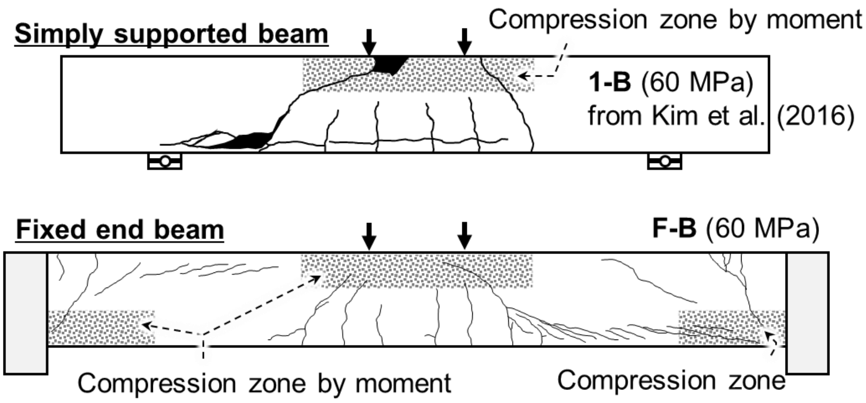


Fig. 6 Failure modes of RC beams with different support conditions

5. CONCLUSIONS

The shear strength of PC-CIP composite beams with different concrete strength (24 MPa and 60 MPa) and fixed support condition was experimentally evaluated. The major findings are as follows.

1) The fixed beams developed flexural cracks and splitting cracks along upper longitudinal rebars due to the negative bending moment at both ends. In particular, the sections A, C, and D with 24 MPa at the upper zone showed severe splitting failure along upper longitudinal rebars. On the other hand, the section B with 60 MPa showed diagonal shear cracking with splitting cracking along lower longitudinal rebars. Splitting cracks along upper longitudinal rebars with 24 MPa concrete decreased shear strength of composite beams.

2) Current design code significantly underestimated the test results of composite beams with fixed ends. Unlike simply supported beams, since the fixed end beams form the additional compression zone at both ends, the effect of support conditions on shear strength should be considered. Further study should be needed.

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