# DEVELOPMENT OF COMPOSITE BEAMS USING ULTRA-HIGH PERFORMANCE FIBER REINFORCED CONCRETE AND FIBER REINFORCED POLYMERS

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## 1. INTRODUCTION

Fiber reinforced polymer (FRP) has recently been adopted in many pedestrian and road bridges due to its light weight, high specific strength, and corrosion resistance. Presently, a hybrid FRP (HFRP) beam for bridge girder applications is being developed. This beam optimizes the combined use of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) in a single wide-flange beam section (Hai et al. 2010). While CFRP has high tensile strength and stiffness, it is relatively expensive, whereas GFRP is comparatively less expensive but its mechanical properties are lower than those of CFRP. In a beam subjected to bending moment about the strong axis, the top and bottom flanges are subjected to high axial stress while the web is subjected to shear stress. Therefore, the top and bottom flanges of a HFRP beam are fabricated using a combination of CFRP and GFRP layers. On the other hand, the web is composed entirely of GFRP because it is not subjected to the same high stress. Although the top flange of a HFRP beam does not utilize the tensile capacity of CFRP, the bottom flange utilizes the advantages of CFRP. That is, the top flange of a HFRP beam is not economical. Also, due manufacturing limitations it is impossible to produce a HFRP beam with HFRP top flange and CFRP bottom flange. Therefore, to improve the effectiveness of a GFRP beam, only the bottom flange should be improved using GFRP or CFRP plates. Past study has shown that a topping slab prevents the top flange delamination of GFRP beams due to compressive stress (Hai et al. 2010). Therefore, the purpose of this paper is to present the flexural behavior of reinforced GFRP beams with a topping slab. Precast ultra-high performance fiber reinforced concrete (UHPFRC) segments are used for the topping slab.

## 2. EXPERIMENTAL PROGRAM

### 2.1 Materials

The overall height of the GFRP I-beam is 250mm and the flange thickness is 9mm as shown in Fig. 1. The test variables for the beam flexural tests are listed in Table 1. Beams G-10, GG-10, and GC-10 were fabricated with precast UHPFRC segments. Precast UHPFRC segments were installed using headed bolts with epoxy bonding. Beam G-only was used as the control specimen without a topping slab. The bottom flanges of beam GG-10 and GC-10 were reinforced using GFRP and CFRP plates respectively. The compressive strength, splitting tensile strength, and Young's modulus of UHPFRC were 173 MPa, 14.3 MPa, and 48.6 GPa respectively.

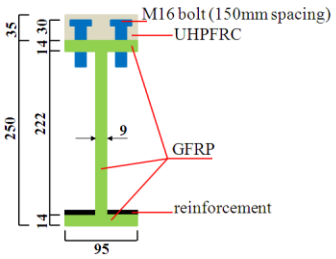


Fig. 1 Dimensions of GFRP I-beam (unit: mm)

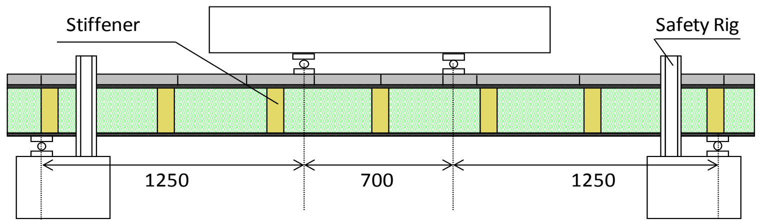


Fig. 2 Geometry of specimen for flexural test (unit: mm)

### 2.2 Test program

The beams were simply supported and tested in four-point bending at a span of 1250 mm with an interior loading span of 700 mm. Web stiffeners were installed at a spacing of 500mm on both side of the web to prevent crippling and warping at the supports and local failure at the loading points. The timber stiffeners were bonded with FRP beam by epoxy adhesion. The test setup is shown schematically in Fig. 2.

Table 1 Test variables

| Specimen | Flange thickness (mm) | Reinforcement |
|---|---|---|
| G-only | 14 | - |
| G-10 | 14 | - |
| GG-10 | 14+8 | GFRP plate |
| GC-10 | 14+1.2 | CFRP plate |

The load was applied by a manually operated hydraulic jack until beam failure. The applied load, deflection at mid-span, and strains in the GFRP beam section were measured.

## 3. TEST RESULTS AND DISCUSSION

Fig.3 shows the load and mid-span deflection relationship of each specimen. For comparison, the load-deflection relation

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curve for a HFRP beam with UHPFRC slab (predicted using fiber model, JSCE 2004) is also included in Fig. 3. The failure load of beam G-10 was 84% higher than that of beam G-only. This increase was due to the topping slab. The failure load of beams G-10, GG-10, and GC-10 were approximately same. However, the deflection of beams GG-10 and GC-10 at the failure load was 28-30% lower than that of beam G-10. This reduction was due to the increase in the stiffness of beams GG-10 and GC-10. The load-deflection behavior of beams GG-10 and GC-10 was similar and the deflection at the failure load was the same as that of the HFRP beam with UHPFRC slab. In brief, flexural stiffness of GFRP beams (GG-10 and GC-10) was improved due to reinforced bottom flange.

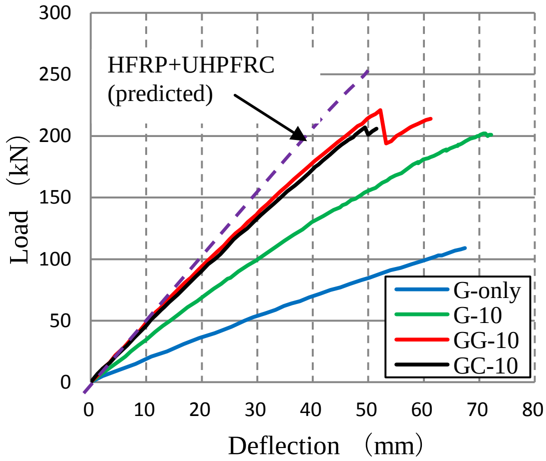


Fig. 3 Load-deflection relationship of GFRP beams

Fig.4 shows the load-longitudinal strain behavior at the top and bottom of the flange at the mid-span section of GFRP beams. The results indicate that both compressive and tensile strain behave linearly up to the failure. However, in this study, authors' main focus was on tensile behavior due to reinforced bottom flanges of GFRP beams. According to Arai 2012, the ultimate tensile strain of GFRP with GFRP plate (GG), GFRP with CFRP plate (GC), and GFRP was $2.01 \times 10^{-2}$, $1.68 \times 10^{-2}$, and $2.19 \times 10^{-2}$ respectively. Therefore, the maximum strain at the bottom flange of beams G-only, G-10, GG-10, and GC-10 was 34, 50, 42, and 42% of ultimate tensile strain. That is, further development is needed in order to utilize the strength GFRP.

Fiber model analysis of GFRP beams with UHPFRC topping slab was conducted and results were compared with the experimental results. Bi-linear stress-strain relationship from JSCE design code was used to model UHPFRC (JSCE 2004). The difference in failure load between the analysis and experiment are less than 15% as shown in Fig. 5.

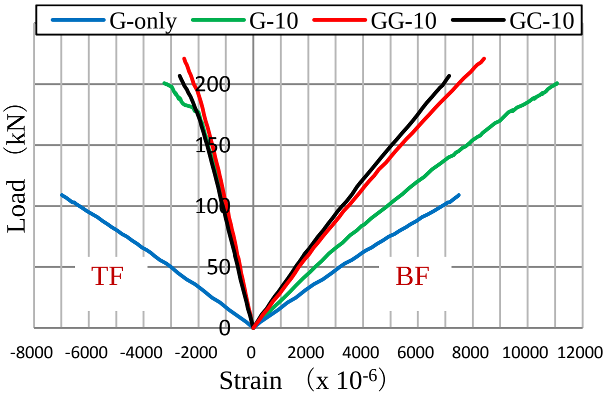


Fig. 4 Load-strain (mid-span) relationship of GFRP beams
BF: Bottom flange (tensile strain)
TF: Top flange (compressive strain)

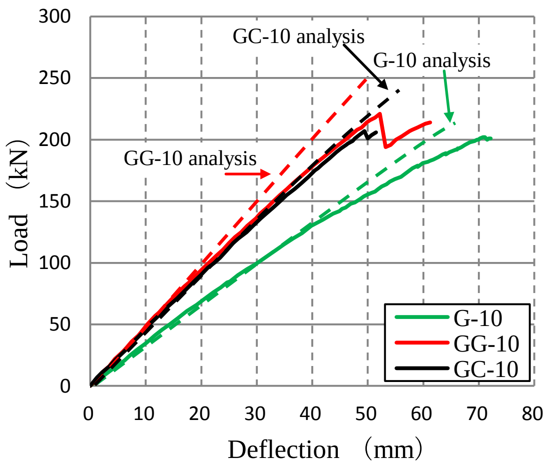


Fig. 5 Comparison of load-deflection curves between experiment and analysis

## 4. CONCLUSIONS

This paper presents an experimental study of GFRP beams with precast UHPFRC topping slabs connected by bolts with epoxy bonding. Based on test results, the following conclusions can be drawn.

1. The failure load of GFRP beams with precast UHPFRC topping slab was 84% higher than that of the GFRP beam.
2. The flexural stiffness of GFRP beams was improved by reinforcing the bottom flange with GFRP and CFRP plates. Therefore, the deflection of GFRP beams with reinforced bottom flange at the failure load was 28-30% lower than that of the GFRP beam.
3. Fiber model can predict the failure load of GFRP beams with precast UHPFRC topping slab.

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