*-Technical paper-*

# EXPERIMENTAL STUDY ON COMPOSITE PC BEAMS BY APPLYING UFC TRUSS AS WEB MEMBER

Chunyakom SIVALEEPUNTH*1, Hiroshi MURATA*1,
Junichiro NIWA*2 and Tetsuo KAWAGUCHI*3

**ABSTRACT:** The aim of this research is to determine the suitable joint method between flange and web, and to investigate the behavior of composite prestressed concrete (PC) beams by applying Ultra High Strength Fiber Reinforced Cementitious Composites (UFC) truss as web member. The study compared the volume of UFC web and the shape of web member. The main results of the study indicate that applying UFC truss as web member gives a higher loading capacity comparing to composite PC beams with triangle web panel.
**KEYWORDS:** Ultra High Strength Fiber Reinforced Cementitious Composites (UFC), joint method, truss member, prestressed concrete

## 1. INTRODUCTION

Ultra High Strength Fiber Reinforced Cementitious Composites (UFC) has been developed since 1994. This material gives highly advanced mechanical properties, superior physical characteristics and unprecedented ductility. Kawaguchi et al. [1] clearly explained that due to the out of range unique mechanical properties of UFC, the composite PC bridge made of this material can enormously reduce the weight of the structure comparing to a RC structure. Not only to reduce the weight of a structure, but it also has been proven to be of practical in its durability in various environments [2][3]; however, little attention has been paid to the problem of construction process.

In this study, by applying UFC truss as web member, the composite PC I-beams with perforated web are examined. The self-weight of beams can be reduced. Due to innovation of UFC, this paper gives some guidelines of using UFC in composite structures for design and construction in future. This paper addressed the suitable joint method and the behavior of composite PC beams by applying UFC truss as web member when the volume of UFC was changed. The study compared the volume of UFC and the shape of the web member (triangle panel), which had been done by Kawaguchi et al. [1].

We start with a brief overview in experiments procedure, followed by the discussion of the mode of failure in different shapes of web panels; those are truss panel and triangle panel. The stress flow, crack pattern, mode of failure and comparison with conventional PC I-beams will be described. Finally, we present some tentative conclusions and recommendations for the further study.

## 2. EXPERIMENTAL PROCEDURES

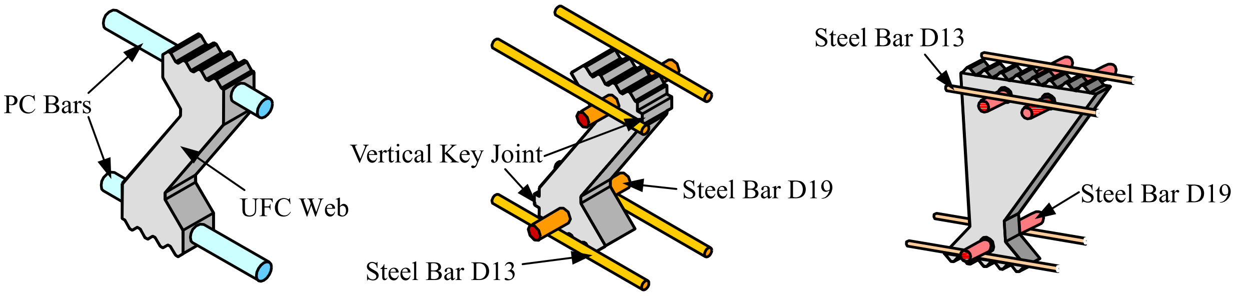
In this study, there were 3 specimens of composite PC beams using UFC truss as web member were cast and named as specimen No. 1, 2 and 3 as shown in **Table 1**. For the later 3 specimens (specimens No. 4 - No. 6), the experimental results were obtained from Kawaguchi et al. [1]. There were 3 parameters, which were considered in this study; those were joint methods between flange and web, shape of web panel and the volume of UFC in web.

**Figure 1** illustrates three types of joint method. Those are the penetration of PC bar key joint (Joint A), the reinforcing bar with vertical key joint (Joint B) and the reinforcing bar without vertical

*1 Department of Civil Engineering, Tokyo Institute of Technology, Member of JCI
*2 Department of Civil Engineering, Tokyo Institute of Technology, Prof. Dr., Member of JCI
*3 Central Research and Development Center, Taiheiyo Cement Corporation, Member of JCI

**Table 1 Test parameters**

| Specimen No. | Shape of web panel | Key joint method (See **Fig. 1**) | | | Volume of UFC in web ($T$=12,800cm$^3$) | | | Lower fiber stress (MPa) | |
|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | 0.5T | 0.67T | T | 5 | 10 |
| 1 | Truss | ◎ | | | | | ◎ | ◎ | |
| 2 | Truss | | ◎ | | | | ◎ | ◎ | |
| 3 | Truss | | ◎ | | | ◎ | | ◎ | |
| 4 | Triangle | | | ◎ | ◎ | | | ◎ | |
| 5 | Triangle | | | ◎ | | | ◎ | ◎ | |
| 6 | Triangle | | | ◎ | | | ◎ | | ◎ |




**Joint A**: Penetration of PC bar key joint

**Joint B**: Reinforcing bar with vertical key joint

**Joint C**: Reinforcing bar without vertical key joint

**Fig. 1 Three types of joint method**

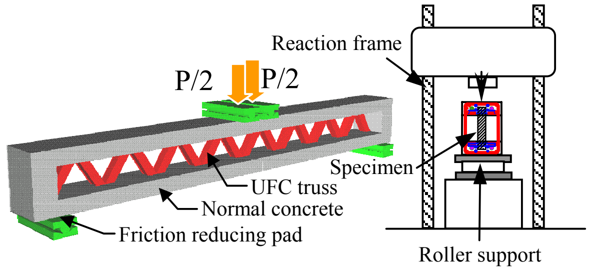



**Fig. 2 Flexure-shear test of composite beams**

**Table 2 Mix proportion of UFC in web (kg/m$^3$)**

| Specimen No. | Water | Premix | Steel fiber | Superplasticizer (SP) |
|---|---|---|---|---|
| 1-3 | 180 | 2254 | 157 | 26 |
| 4-6 | 180 | 2297 | 157 | 23 |

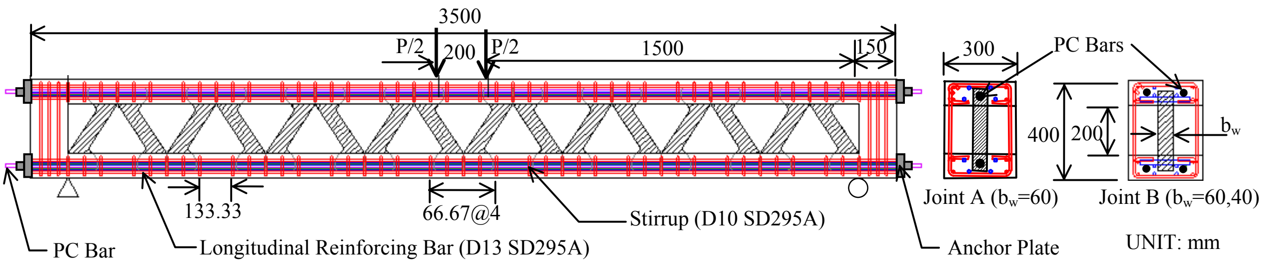



**Fig. 3 Experimental outlines**

key joint (Joint C). The test of simply supported composite PC beams under two points load was performed to compare the joint A (Specimen No. 1) and the joint B (Specimen No. 2). The vertical force, P/2, was applied monotonically to the specimen with two loading points as shown in **Fig. 2**. In order to reduce the friction at the supports, friction-reducing pads, i.e., two Teflon sheets (0.05mm thickness) sandwiching silicon grease, were inserted between the specimen and the support plates. After obtained the suitable joint method, the specimen No. 3 was cast and the volume of UFC in web member, which was a precast member, was a next parameter to study.

In the web of composite PC beams, UFC was introduced because of its superior strength (compressive strength = 200MPa) combined with high shear carrying capacity. It results in significant dead load reduction and provides nearly limitless structural member shape. The mix proportion of UFC truss member is shown in **Table 2**. The mixing time of UFC is about 12-14 minutes. There is no segregation and sinking of steel fiber from the matrix due to its high viscosity. After casting into the formwork, the formwork was covered by plastic sheet and put into the chamber, which the temperature was controlled at 20 degree Celsius for 48 hours. After the formwork was removed, the specimens were cured again with 100% humidity at 90 degree Celsius for 48 hours.

The experimental outlines were depicted in **Fig. 3**. The shear span for all specimens was set as 1500mm;

**Table 3 Mix proportion of flange concrete ($kg/m^3$)**

| No. | Water | Early high-strength cement | Fine aggregate | Coarse aggregate | Superplasticizer (SP) |
|---|---|---|---|---|---|
| 1-3 | 170 | 567 | 871 | 765 | 9.1 |
| 4-6 | 151 | 583 | 823 | 875 | 5.8 |

**Table 5 Material properties in flange**

| | Specific gravity |
|---|---|
| Early high strength cement | 3.16 |
| Fine aggregate# | 2.63 |
| Coarse aggregate* | 2.63 |
| Superplasticizer (SP) | 1.10 |
| Ordinary portland cement | 3.15 |
| Admixture | 1.44 |

#F.M.=2.5

*Oume Aggregate, F.M.=6.9, $G_{max}$=15mm

**Table 4 Mix proportion of grout ($kg/m^3$)**

| Water | Ordinary portland cement | Admixture |
|---|---|---|
| 587 | 1305 | 13 |

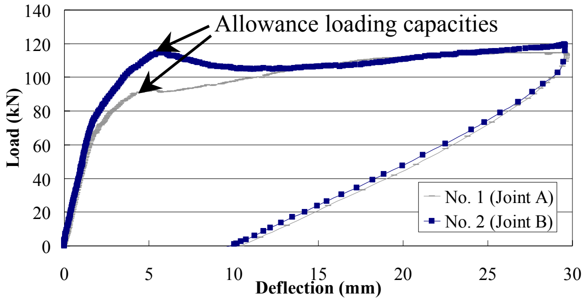



**Fig 4. Load-deflection curve of beams with Joint A and with Joint B**

the effective depth was 350mm; therefore, shear span to effective depth ratio was 4.29. In specimen No. 1 (Joint A), two of ϕ17 PC bars (SBPR1080/1230; $f_y$ = 1229MPa, $E_s$ = 200GPa) were applied to both top and bottom flanges (One bar in each flange). The longitudinal reinforcement ratio was 1.89%. In specimens No.2 and 3 (Joint B), four of ϕ13 PC bars (SBPR1080/1230; $f_y$ = 1243MPa, $E_s$ = 201GPa) were applied to both top and bottom flanges (Two bars in each flange). The longitudinal reinforcement ratio was 1.86%. For specimens No. 4-6, two of ϕ29 PC bars ($f_y$ = 1120MPa, $E_s$ = 210GPa) were applied at the bottom flange by using NAPP method (pretension method) [1]. For all specimens, the deformed bar with 10mm in diameter (SD295A, $f_y$ = 349MPa, $E_s$ = 206GPa) was used for shear reinforcement in both top and bottom flanges. The shear reinforcement ratio in the flange was 0.6% for specimens No. 1-3 and 0.3% for specimens No. 4-6 (There is no reinforcement bar in the web).

**Table 3**, **Table 4** and **Table 5** tabulate the mix proportion of concrete used in flange, the mix proportion of grouting cement paste in flange and the material properties in flange, respectively. Before casting the flange of specimens No. 1-3, the precast UFC truss web members were arranged and connected with each other by using epoxy. After casting the flange part, the specimens were cured for 7 days. And then the prestressing force was applied to both top fiber and bottom fiber flanges in order to generate 3MPa and 5MPa in compression as the upper and lower fiber stresses, respectively. For all specimens, grouting of cement paste was proceeded. After that, specimens were cured for another 7 days, thus curing period of concrete in flange was 14 days before loading.

## 3. RESULTS AND DISCUSSIONS

### 3.1 CONSIDERATION OF JOINT METHOD

As the first step, the comparison of the penetration of PC bar key joint (Joint A) and the reinforcing bar with vertical key joint (Joint B) was considered. From the previous study, it was found that there was not only sliding in horizontal direction, but also in vertical direction among web panels itself. Therefore, the vertical key joint was introduced in this study. From the experimental results of beams with joint A and with joint B, the allowance loading capacities, $P_a$, (not the maximum loading capacities) were 92.5kN and115kN, respectively. **Figure 4** illustrates the load-deflection curve of beams with joint A and with joint B. According to the load-deflection curve, from the beginning, the curves steeply rise up to the relative maximum points, defined as the allowance loading capacities, $P_a$. It should be noted that at this point the allowance loading capacities of both beams gave the different results. After that the loads fell abruptly until it reached the stable condition, and then gradually increased again. This behavior can be explained in **Fig. 5**. It can be observed from the strain in UFC truss that the behavior of beams was not the truss structure anymore after the allowance loading capacity. After the deflection of beams was 13mm, the behavior of beams with joint A and with joint B tended to be the same, that is bending force in compression web member, until reached the maximum load in the viewpoint of load-deflection curve. For the safety in testing, the specimens No. 1-3 were loaded up to the displacement equal to 30mm. From **Fig. 6**, it clearly shows the stresses, which flow throughout the truss and triangle panel web members. These stress flows create both

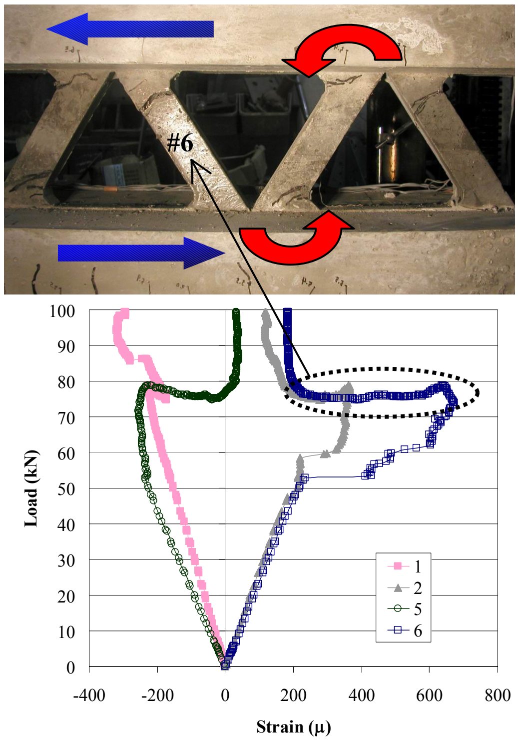



**Fig. 5 UFC truss strain of specimen No.3 (Gauge position shows in Fig. 6)**

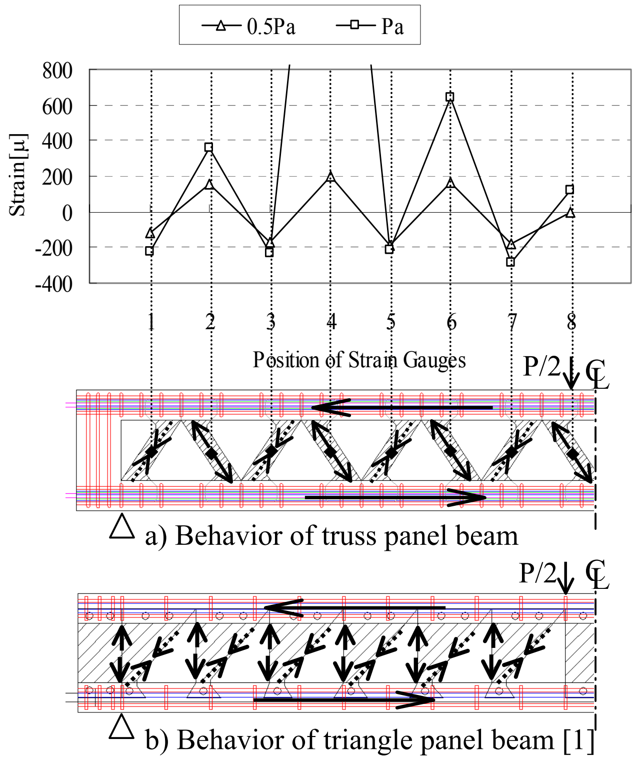



**Fig. 6 Behavior of composite PC beams by applying UFC as perforated web member**

horizontal and vertical sliding among the webs and flanges. Therefore, it should be noted that if the joint method is not sufficiently provided, it may lead to the failure of joint between web and flange. Because of higher loading capacity of a beam with joint B, joint B was concluded to be the suitable joint method to pursue in the study of the UFC amount effect as a web member for specimen No. 3.

### 3.2 INFLUENCE OF PANEL SHAPE AND CRACKING BEHAVIOR

**Figure 6** indicates the behavior of truss panel beam against the behavior of triangle panel beam. It can be noticed that in the case of triangle panel, when the load was applied up to some level, the crack started to penetrate at the tensile resisting portion of UFC web member due to both tensile and bending force. By increasing load, this crack was getting larger and penetrated more into the compressive resisting portion of UFC web member.

In the case of truss panel beams, the cracking patterns were illustrated in **Fig. 7**. The firstly formed crack was the flexural crack near or at the mid-span of the bottom flange where is the section of the maximum moment. By increasing load, the crack occurred at tensile truss member near to the loading point. After increasing more load until the load reached the allowance loading capacity, the crack occurred simultaneously at the next tensile truss member until the last tensile member near to the support. Then the load dropped until some level. The crack at the tensile truss member became larger. The crack started to penetrate into the compressive truss member due to the bending force. The load increased again, even though the crack at the tensile truss member was completely opened. This may be due to a variety of factors, such as the joint method and the separation of tension and compression members. Thus, the stress can transfer from the loading point to the support through the compression member, even though there is no tension member.

The ultimate capacity of six specimens is summarized in **Table 6**. From specimens No. 5 and 6 (triangle panel beams), it was clearly observed in **Fig. 8** that even though the lower fiber stress was increased to 10MPa, there was no influence on the loading capacity of the beams because the failure mode was unchanged, which was the tension failure in web member [1]. This is the main reason to set the lower fiber stress in specimens No. 1-3 (truss panel beams) as 5MPa in this study.

Moreover, from **Fig. 8**, it is confirmed that the truss panel beam provided a higher loading capacity than the triangle panel beams. Perhaps most surprisingly, very high ductility of truss panel beams could be observed when comparing to the case of triangle panel beams. As explained previously, it may be due to the separation of compression member and tension member.

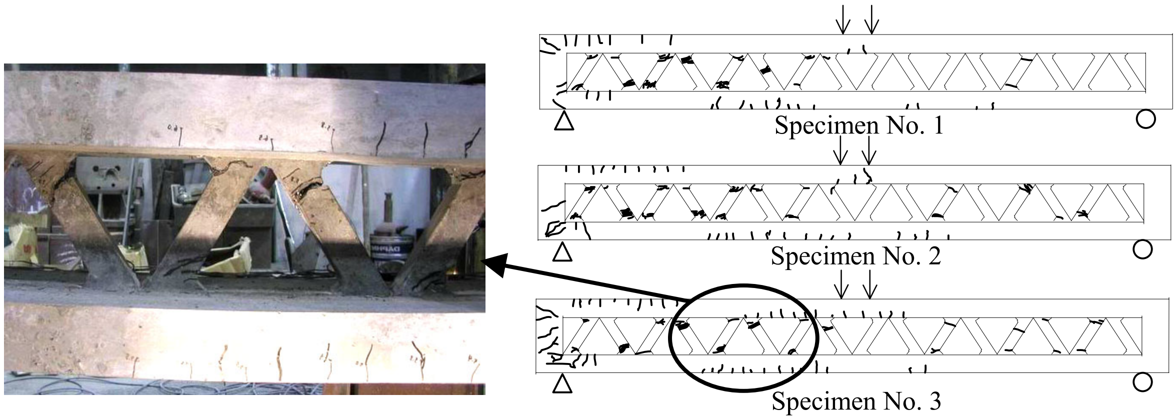



**Fig. 7 Crack patterns of composite PC beams by applying truss as web member**

**Table 6 Loading capacities for composite PC beams and material strength**

| Specimen No. | Joint Method (See **Fig.1**) | Loading Capacity, $P_{max}$ (kN) | Concrete in Flange | | | UFC in Web | | |
|---|---|---|---|---|---|---|---|---|
| | | | $f_c$' (MPa) | $f_t$ (MPa) | $E_s$ (GPa) | $f_c$'(MPa) | $f_t$ (MPa) | $E_s$(GPa) |
| 1 | A | $92.5^*/115.0^\#$ | 71.2 | 3.2 | 34.3 | 195.1 | 8.8 | 52.9 |
| 2 | B | $115.0^*/119.6^\#$ | 69.1 | 3.5 | 32.9 | 195.1 | 8.8 | 52.9 |
| 3 | B | $78.8^*/99.4^\#$ | 77.3 | 3.1 | 32.3 | 206.7 | 7.6 | 53.3 |
| 4 | C | 70.4 | 70.2 | 3.5 | 36.6 | 204.5 | 10.9 | 49.8 |
| 5 | C | 105.4 | 72.4 | 4.2 | 37.1 | 207.5 | 12.9 | 50.8 |
| 6 | C | 102.9 | 75.3 | 4.5 | 37.4 | 202.9 | 11.6 | 50.2 |

* Allowance loading capacity, $P_a$
\# Maximum load at displacement was reached 30mm, $P_{max}$

$f_c$': compressive strength of concrete $f_t$: tensile strength of concrete
$E_s$: Young's modulus of concrete

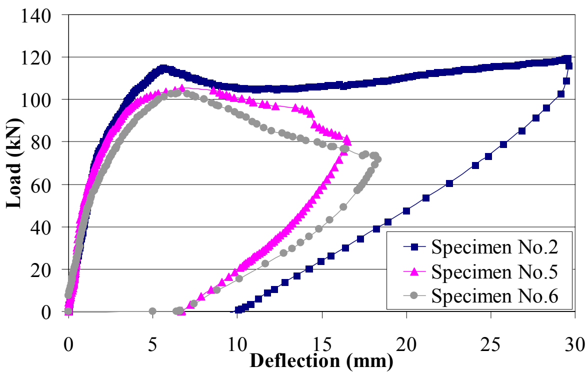



**Fig. 8 Load-deflection curve by comparing the truss member with triangle panel [1]**

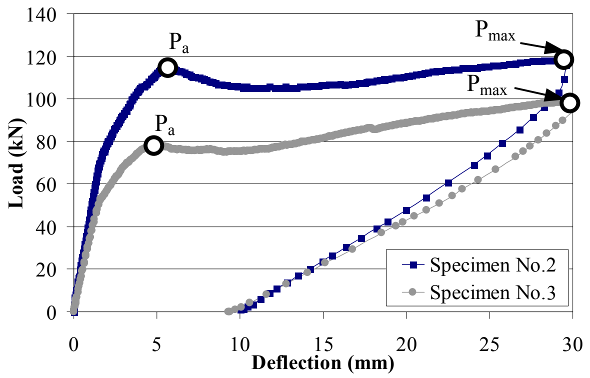



**Fig. 9 Load-deflection curve by comparing the UFC volume of truss member**

### 3.3 INFLUENCE OF UFC VOLUME IN WEB MEMBER

By comparing the volume of UFC as a web member, when the volume of UFC used in specimen No. 2 was decreased by one-third, the loading capacity of a truss panel beam (specimen No. 3) decreased by about one-third of its capacity as shown in **Fig. 9**. In addition, Kawaguchi et al. [1] also confirmed based on his experimental results that when the volume of UFC in web was reduced about a half, the loading capacity of beams also decreased into a half as comparing in specimen No. 4 and specimen No. 5.

## 4. COMPARISION WITH THE CONVENTIONAL PRESTRESSED CONCRETE I-BEAMS

In order to confirm that the composite PC I-beams with the use of perforated UFC web (Specimens No. 2-3) give a lighter weight than the conventional PC I-beams with the use of solid web at the same load carrying capacity, the calculation of the conventional PC I-beams is performed by using JSCE design code 2002 [4].

The characteristics of designed PC I-beams are set to be the same as in the composite PC I-beams. The only difference is that instead of using UFC truss as web, the solid web of the designed PC I-beams will use the same concrete as used in the flange as shown in **Fig. 10**. The shear carrying capacity, $V_{yd}$, of PC I-beams

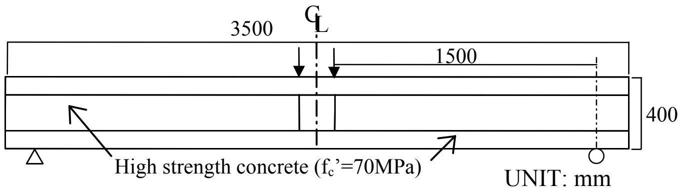



**Fig. 10 Outline of PC I-beam**

**Table 7 Designed results of PC I-beams**

| No. | Max. Load (kN) | $b_w$ of PC beam (mm) | UFC web weight (kg) | PC beam web weight (kg) | Weight reduction (%) |
|---|---|---|---|---|---|
| 2 | 119.5 | 49.7 | 33 | 79.5 | 58.5 |
| 3 | 99.4 | 37.7 | 22 | 60.3 | 63.5 |

*$b_w$=Web thickness

can be obtained from the following **Eqs. (1)** and **(2)** [4].

$$V_{yd} = V_{cd} + V_{sd} \tag{1}$$

$$V_{cd} = \left(1 + 2M_0/M_u\right)0.2\left(f'_{cd}\right)^{1/3}\left(1000/d\right)^{1/4}\left(100P_w\right)^{1/3} b_w d \tag{2}$$

where, $V_{sd}$: shear carrying capacity due to stirrup, $M_0$: decompression moment, $M_u$: ultimate moment, $f'_{cd}$: compressive strength of concrete (MPa), d: effective depth (mm), $P_w$: longitudinal reinforcement ratio $\left(= A_s/\left(b_w \cdot d\right)\right)$, and $b_w$: web thickness (mm)

Hence, there is no stirrup provided; $V_{sd} = 0$. To determine the web thickness of PC I-beams, the maximum load was obtained at $P_{max}$ as shown in **Fig. 9**. The weights of the web member of PC I-beams and composite PC I-beams were compared by using the densities of concrete and UFC as 2.5t/m$^3$ as shown in **Table 7**. It is found that the weight of the web member can be reduced to 55-65% by the use of perforated UFC web. This implies that the self-weight of a web member of the composite PC girder using UFC truss is enormously reduced compared with those of PC girders.

## 5. CONCLUSIONS

The experimental investigation of composite PC beams by applying UFC truss as web member was carried out to demonstrate some guidelines of the advanced design and construction process in the use of UFC precast web panel. The followings can be concluded from this study.

- UFC truss web member in composite PC beams has been proven to be one of the suitable construction processes, which gives the lightweight to the structure and easy to apply in construction site due to precast members of UFC.
- The reinforcing bar with vertical key joint is suggested to be the suitable joint method in this study.
- By reducing one-third of UFC volume in web, the loading capacity also reduces into one-third.
- By comparing the truss web panel beams with the triangle web panel beams, the truss web panel beams give a higher loading capacity and ductility.

## ACKNOWLEDGMENTS

Sincere gratitude is expressed to Oriental Construction Co., Ltd. for their cooperation.

## REFERENCES

1. Kawaguchi, T. et al., "Experimental Research on Mechanical Properties of Composite PC Members Using UHSFRCC," Proceedings of the JCI, Vol. 25, No. 2, 2003, pp. 1987-1992.
2. Roux, N., Andrade, C. and Sanjuan M. A., "Experimental Study of Durability of Reactive Powder Concretes," Journal of Materials in Civil Engineering, Vol. 8, Issue 1, Feb. 1996, pp. 1-6.
3. Tanaka, Y. et al., "Design and Construction of Sakata-mirai Footbridge Using Reactive Powder Concrete," Proceedings of the First fib Congress, Vol. 3, 2002, pp. 417-424.
4. JSCE (JSCE CODE), "Structural Performance Verification, Standard Specification for Concrete Structures, 2002."