Shear-Resistance Mechanism of Reinforced Concrete Beam with U-shaped ECC Permanent Formwork

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1. INTRODUCTION

Engineered Cementitious Composites (ECC) is a type of High Performance Fiber Reinforced Cementitious Composites (HPFRCC), which exhibits strain hardening behavior with closely-spaced multiply cracks under uniaxial tensile stress [1]. The purpose of this study is to develop new construction type with using ECC as U-shaped precast permanent formwork, especially for shear. This paper focused on the ability to convert a crack with remarkable width into multiple fine cracks and the effect of inner surface of U-shaped precast ECC formwork on the shear-resistance mechanism.

2. EXPERIMENTAL PROGRAM

(1) Specimen preparation and details

Fig. 1 illustrates the detail of a tested beam. Two beams component compound with U-shaped permanent formwork and reinforced concrete (RC) were prepared. Two ECC U-shaped sections with 40 mm thickness in both sides and bottom and different internal surface forms were cast with upside down direction. **Fig. 1** demonstrates two different kinds of internal surface of U-shaped ECC. These include the surface with shear key connectors in both vertical direction and bottom surface with 200 mm interval spacing and horizontal direction with 80 mm interval spacing (U40-K), and smooth surface (U40-S). The dimension and location of shear key are shown in **Fig. 2**. All the specimens were demolded after 24 hours and cured with water-spray for 14 days. Then concrete and D22 longitudinal steel bars were filled and cured until the concrete age of 7 days. **Table 1** lists the detail of mix proportion. The designed strength of concrete was 35 N/mm^2.

Table 1 Mix proportion

G_{max} (mm)	W/C	Unit weight (kg/m^3)						
		W	C	LP	S	CA	SP	V
13	0.6	165	292	249	718	857	4.38	0.25

W:Water *C*:Cement *LP*:Lime stone powder, *S*:sand, *CA*:Coarse Aggregate *SP*: superplasticizer, *V*:Viscosity improver

(2) Instrumentation and test procedures

Four-point bending tests of two beams were conducted. Loaded specimens were monitored in terms of applied load, mid-span deflection, strain of concrete and ECC on top fiber, longitudinal bars. And also horizontal displacements and crack width was measured by using transducers on the bottom fiber of beam and interface of ECC and concrete along the shear span. The crack propagation on the side surface of test-span during loading was recorded by taken pictures.

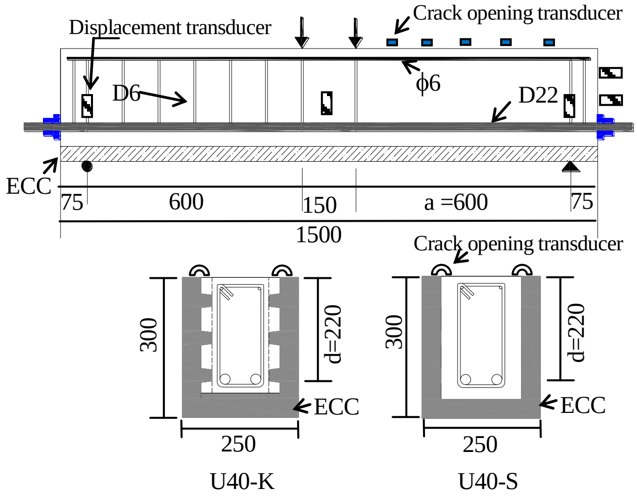

Fig.1 Detail of beam specimens (unit: mm)

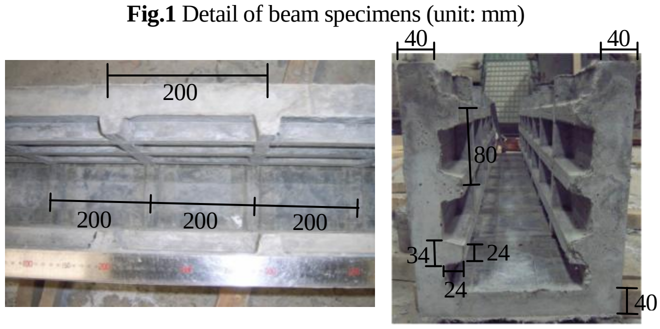

Fig.2 Detail of shear key connectors (unit: mm)

Table 2 Summary of experimental results

Specimen	f_c' Conc (N/mm^2)	f_c' ECC (N/mm^2)	Load at Flexural Crack (kN)	Load at Diagonal Crack (kN)	Load at Peak (kN)
U40-K	37.3	29.5	50	190	300.8
U40-S	39.0	28.4	63	185	274.6

keywords: ECC, Permanent formwork, Shear key connector, Precast , Diagonal crack
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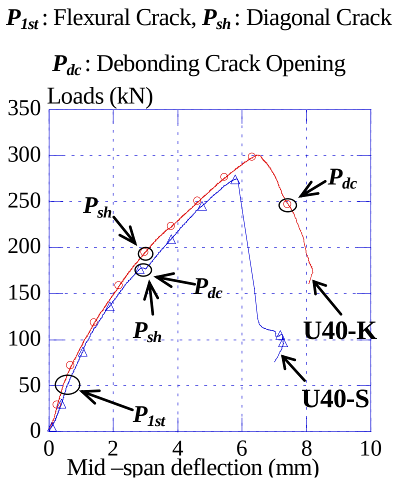

Fig. 3 Load-displacement curve

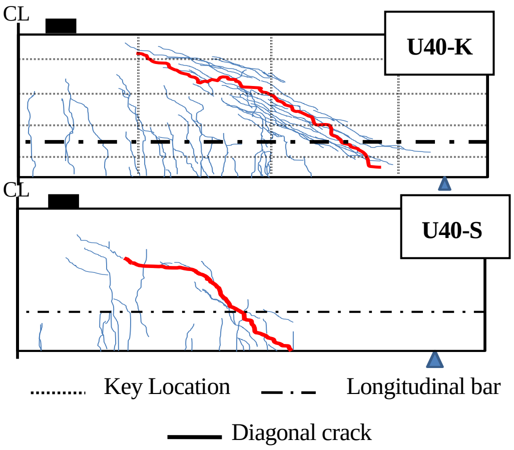

Fig. 4 Crack patterns

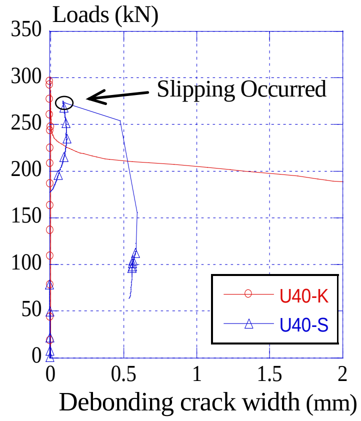

Fig. 5 Load-debonding crack width

3. EXPERIMENTAL RESULTS AND DISCUSSION

(1) Load-displacement relationship and crack patterns

Results of loading tests, compressive strength of concrete and ECC are presented in **Table 2.** Load-displacement relationship is illustrated in **Fig. 3**. The shapes of load-displacement curves for both specimens look similar. However, significantly different cracks patterns can be observed in the experiments. **Fig.4** indicates the crack distribution captured at the peak.

The development of failure in U40-K is demonstrated as follows. First, the specimen behaved in elastic manner until flexural cracks initiated when the load reached 50 kN around mid-span, flexural and flexural shear fine cracks appeared in a sequence from the mid-span to support, which decreased the inclination of the curve. Second, when the load reached 190 kN, the visible fine inclined cracks which initiated in the shear span were propagated along the line between the support to the loading points, the increase in the number of cracks can be observed as shown in **Fig. 4**. Third stage, the multiple cracks were integrated into a diagonal crack and propagated and widened until the specimen failed. Interface debonding cracks between ECC and concrete were not observed. However, visible debonding appeared and became wider after the peak.

In U40-S, before the diagonal crack occurred, the specimen showed similar crack distributions. When the applied load reached 185 kN, the diagonal crack was propagated and widen until the peak load as shown in **Fig.4**.

In comparison, before the diagonal crack occurred, the number of multiple cracks in U40-K was larger than that of U40-S. Moreover, the data from the horizontal LVDT located at the half of depth of a beam showed the larger difference between concrete and ECC since the diagonal crack occurred, with same agreement from debonding crack width from transducers that the gap propagated and became larger as shown in **Fig. 5**. As a result, at the peak point, slipping between two sections occurred and the applied load suddenly decreased with a slight increase in displacement.

(2) Effect of internal surface of ECC formwork

From the load-displacement curve in **Fig. 3** shows that the surface condition slightly affected the shear capacity, but it affected the crack propagation of specimens. As mentioned with U40-S, the debonding crack propagated before the peak load and caused slipping between two sections, however in case of U40-K debonding crack appeared in the post peak region, furthermore, many multiple fines cracks were developed.

4. CONCLUSIONS

(1) The U-shaped ECC permanent formwork is effective to change the main single opening crack in concrete into fine multiple cracks in ECC.

(2) The distribution of shear keys on internal surface of ECC can improve brittle failure of composite beam.

REFERENCES

[1] Japan Society of Civil Engineers (JSCE): *Recommendations for Design and Construction of High Performance Fiber Reinforced Cement Composites with Multiply Fine Cracks (HPFRCC)*, Concrete Engineering Series 82, 2007

[2] Leung C.K.Y., Cao Qian.: "*Development of pseudo-ductile permanent formwork for durable concrete structures*", Materials and Structures Online First, 2009.