Concrete bridge deck slabs strengthened with UHPFRC

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Summary

An original concept is presented for the durable rehabilitation of concrete bridge deck slabs. The main idea is to add a layer of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) with steel reinforcing bars over the concrete slab to create a composite section. The layer of UHPFRC is waterproof and protects the reinforced concrete against severe environmental influences. It also strengthens the structural element for high traffic loads. Experimental studies on composite beams in a cantilever setup were carried out to identify the different failure modes and the contribution of the UHPFRC layer to the resistance. Analytical models were then developed to calculate the resistance of composite beams. The concept has been validated by field applications demonstrating that the technology of UHPFRC is mature for cast in-situ.

Keywords: UHPFRC, composite section, reinforced concrete, resistance, failure mode, analytical model, rehabilitation, strengthening.

1. Introduction

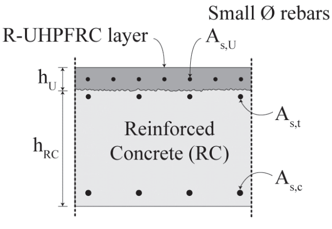

Fig. 1: Typical composite section [1]

To increase the life span of a reinforced concrete bridge deck slab, it is possible to add a layer of 30 to 60 mm of Ultra-High Performance Fiber Reinforced Concretes (UHPFRC) with or without small diameter steel reinforcement bars, to create a composite section (Fig. 1). UHPFRC is a cementitious composite material with excellent properties: extremely low permeability and very high strength. A UHPFRC layer can thus protect the concrete slab against water and chlorides and strengthen it for high traffic loads as proposed in [1].

2. UHPFRC in tension

The uniaxial tensile behaviour of UHPFRC is divided into three phases (Fig. 2): elastic, strain hardening with multiple (non-visible) microcracking of the matrix and fiber activation and finally softening with the opening of a discrete macrocrack.

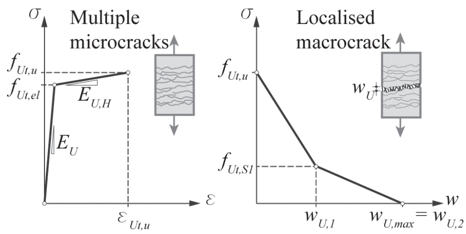

Fig. 2: Tensile behaviour of UHPFRC [1]

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3. Experimental investigation on composite beams

Composite beams were tested in a cantilever test setup (Fig. 3). Beam B_MW4 [2] failed in flexure-shear with a sudden decrease of resistance after the peak load. Beam S_M1 failed in bending keeping a significant proportion of its resistance after peak load. In both cases, the strength of the composite section was higher than that of the equivalent reinforced concrete section.

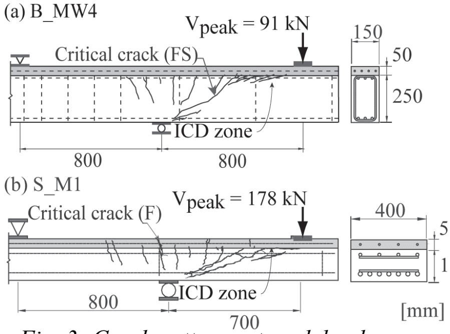

Fig. 3: Crack patterns at peak load

4. Analytical model

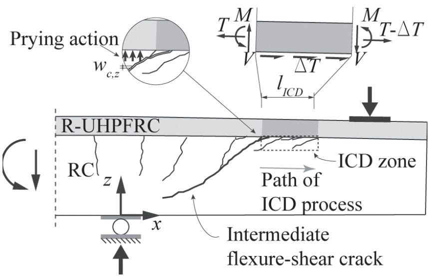

Fig. 4: Intermediate-Crack induced debonding (ICD) [2]

A flexural failure occurs along a vertical crack at the point of highest moment with no debonding at the interface. The resisting moment in bending for a composite beam can thus be calculated with a plane section analysis [1]. A flexure-shear failure occurs with the widening of an inclined crack which causes the Intermediate-Crack induced Debonding (ICD) [2] (Fig. 4). The flexural-shear strength is obtained with the sum of the contribution of concrete (V_C), stirrups in steel (V_s) and UHPFRC layer (V_{RU}) [2]. The layer resists to the ICD by bending and V_{RU} is calculated with the strength in bending ($M_{RU,max}$) and the length of the ICD zone ($l_{RU,db,max}$).

$$V_{RU} = \frac{2M_{RU,max}}{l_{RU,dl,max}} \quad (1)$$

5. Application

A massive slab bridge with 6 columns, built in 1963, in Switzerland, was reinforced with a layer of UHPFRC (Fig. 5). Before the intervention, the slab parts over the column supports did not meet the requirements for structural safety in bending and shear. It was strengthened with a layer of 25 mm of UHPFRC everywhere and a layer of 65 mm with 18 mm diameter rebars over the supports.


Fig. 5: Application

6. Conclusion

A layer of reinforced UHPFRC over a reinforced concrete section significantly increases the load bearing capacity and prevents shear failure if designed correctly with the analytical models. A site application showed that this concept is also simple to apply to full size structures.

7. References

[1] HABEL K. *Structural Behaviour of Elements Combining Ultra-High Performance Fibre-Reinforced Concretes and Concrete*, Doctoral Thesis, No. 3036, EPFL, Switzerland, 2004, p. 195.

[2] NOSHIRAVANI T. *Structural Response of R-UHPFRC – RC Composite Members Subjected to Combined Bending and Shear,* Doctoral Thesis, No. 5246, EPFL, Switzerland, 2012, p. 188.