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Composite UHPFRC-concrete construction – harden structures to last

Summary

An original concept is presented for the rehabilitation of concrete structures. The main idea is to use Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) to “harden” those zones of the structure that are exposed to severe environment and high mechanical loading. All other parts of the structure remain in conventional structural concrete as these parts are subjected to relatively moderate exposure. The concept is validated by means of various applications in Switzerland and most recently Slovenia demonstrating that the technology of UHPFRC is mature for cast in-situ and prefabrication using standard equipment for concrete manufacturing, with local materials, in most challenging execution configurations.

1 Introduction

The increasing volume of European transport urgently requires an effective road and rail system in Central European and Eastern Countries (CEEC) with a major investment in building new and assessing and rehabilitating old structures.

Ultra-High Performance Fiber Reinforced Concretes (UHPFRC), characterized by a very low water/binder ratio, high binder content and an optimized fibrous reinforcement, provide the structural engineer with a unique combination of extremely low permeability, high strength and tensile strain hardening. UHPFRC are perfectly suited to the rehabilitation of reinforced concrete structures in critical zones subjected to an aggressive environment and to significant mechanical stresses, to provide a long-term durability and thus avoid multiple interventions on structures during their service life. Extensive R&D works performed during EU project SAMARIS [1] and various full scale applications in Switzerland [2, 3] on bridges have demonstrated that UHPFRC technology is mature for cast in-situ applications of rehabilitation, using standard equipments.

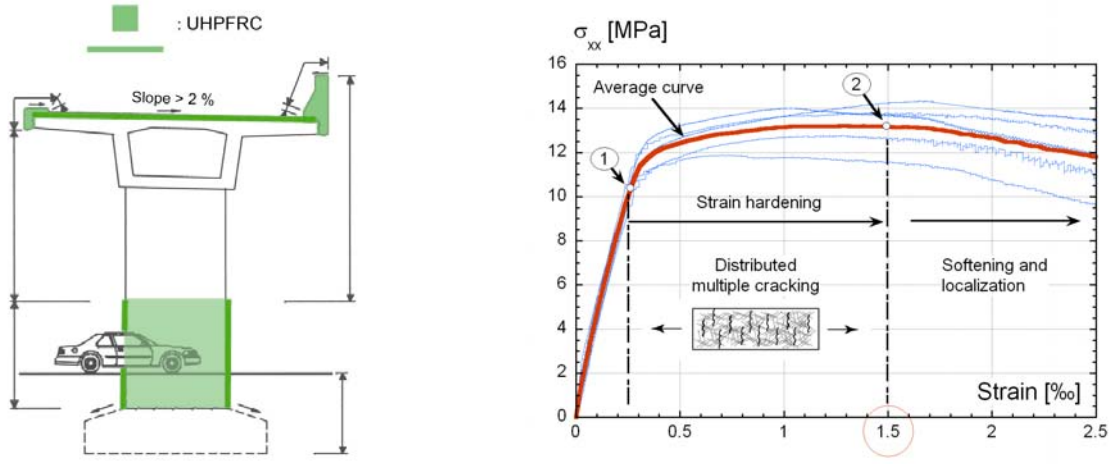
EU Project ARCHES [4] dedicates a significant effort to demonstrate the applicability of this innovative rehabilitation technique in CEEC, with cheaper UHPFRC based on locally available components and improved rheological properties (tolerance to slope of the substrate at fresh state).

Achievement of tensile strain hardening, extremely low permeability and self-compacting character is indeed a challenge that few current UHPFRC recipes can satisfy. An original concept of Ultra High Performance matrix with a high dosage of mineral addition has been developed that makes the application of UHPFRC technology feasible with a wide range of cements and superplasticizers.

In a further step, the rheology of those mixes has been adapted to enable them to accomodate challenging 5 % slopes of the substrates at fresh state. Finally, this new material has been applied to the rehabilitation of a bridge in Slovenia.
This paper reports on the major results achieved in this context with a strong focus on the experiences gathered during full scale applications, in Switzerland since 2004, and most recently in Slovenia, in 2009.

2 Concept of application

The concept of application of UHPFRC for the rehabilitation of structural members, proposed by Brühwiler in 1999, [2] is schematically illustrated on Fig. 1 a). An "everlasting winter coat" is applied on the bridge superstructure in zones of severe environmental and mechanical loads (exposure classes XD2, XD3) and only where the UHPFRC is worth using. Critical steps of the construction process such as application of waterproofing membranes or compaction by vibration can be prevented, and the associated sources of errors avoided. The construction process becomes then simpler, quicker, and more robust, with an optimal use of composite construction. The concept is well-suited for bridges and can also be implemented for buildings, galleries, tunnels or retaining walls.



a) b)

Fig. 1 a) Concept of application of the local "hardening" of bridge superstructures with UHPFRC, b) tensile response of UHPFRC (results from 5 dogbone specimens and average curve, after [3]).

The waterproofing capabilities of the UHPFRC exempt from applying a waterproofing membrane. Thus, the bituminous concrete can be applied after only 8 days of moist curing of the UHPFRC.
This constitutes a very significant time saving with respect to the drying period of up to 3 weeks necessary prior to the application of a waterproofing membrane on a usual mortar or concrete.
Further, the thickness of the bituminous concrete layer can be limited to the absolute minimum necessary for the traffic loads. It is unnecessary to increase it to apply weight on the waterproofing membrane to prevent the formation of air pockets.
When it is required, the combination of the protective properties and deformation capability of UHPFRC (Figgure 1 b) with the mechanical performance of reinforcement bars (normal or high grade) provides a simple and efficient way of increasing the stiffness and load-carrying capacity with compact cross sections [2]. This original conceptual idea has been validated by means of extensive researches aimed at characterizing UHPFRC materials and the structural behaviour of composite structural members (see peer reviewed journal papers at http://mcs.epfl.ch/).

3 Examples of application

A major effort is ongoing in Switzerland to develop optimized combinations of local UHPFRC and reinforcements bars of various grades and apply them for the improvement of existing structures [2]. Up to know, since 2004, five full scale applications have taken place in this single country on various types of structures with different types of UHPFRC ($CEMTEC_{multiscale}$® and $HIFCOM_{EPFL}$ 13s), with or without rebars, [2,3]:

- Rehabilitation and widening of a road bridge: The entire deck surface of the bridge over river "La Morge" with a span of 10 m was rehabilitated with 3 cm UHPFRC during autumn 2004 The analysis of the construction costs showed that the rehabilitation realised with UHPFRC was about 10% more expensive that the conventional solution (providing lower quality in terms of durability and life-cycle costs) with waterproofing membrane and repair mortar. However, in the latter case the duration of the construction site would have been largely increased by the required drying period of the mortar, prior to the application of the waterproofing membrane.
- UHPFRC protection layer on a crash barrier wall: A layer of UHPFRC has been applied in September 2006 to the concrete crash barrier walls of a highway bridge nearby Zürich. The main design requirement was to obtain long-term durable crash barrier walls since traffic interruption for future rehabilitation interventions are prohibitive due to the very high traffic volume on this highway. The rheological properties of UHPFRC were adapted for easy pouring into the 3 cm wide formwork to fill a height of 120 cm including a small horizontal part at the bottom of the wall that provides continuity with the conventional bridge deck with a waterproofing membrane.
- Rehabilitation of a bridge pier using prefabricated UHPFRC shell elements (2007): In this application, 4 cm thick UHPFRC shell elements have been prefabricated to form an outer protection shield for the existing 40 year old reinforced concrete bridge pier nearby Zürich, which is located very closely to busy highway traffic which makes it virtually not accessible for future maintenance interventions.
- Strengthening of an industrial floor (2007): The 50 year-old drivable reinforced concrete floor of a fire brigade building in Geneva had insufficient load carrying capacity in view of heavier future fire engines. The concept to increase the load carrying capacity of the existing slab of 720 m^2 area was to pour a 4 cm thick UHPFRC layer with rebars on top of the existing RC slab, as a replacement of the existing cementitious non-load carrying overlay. The use of the UHPFRC solution turned out to be very economic (compared to the conventional solution of slab demolition and reconstruction), also because the utilization of the fire workers building was only slightly restricted during the intervention and thus user costs could be kept minimal.
- Rehabilitation of bridge "Dalvazza" (2008): The 28.5 m span bridge deck was rehabilitated and strenghtened with a combination of 4 to 8 cm UHPFRC and rebars. Gravel was sprayed on the fresh UHPFRC to obtain a ready to use surface for the traffic, without bituminous pavement.
- Rehabilitation of Log Čezsoški bridge – Slovenia (2009): An innovative concept of cement replacement by high dosages of limestone filler, developped at EPFL, helped break the workability barrier and produce a Slovenian UHPFRC with local cement (SALONIT), and superplasticizer (TKK), based on the $CEMTEC_{multiscale}$® fibrous mixes developped at LCPC (9 % total micro + macro fibres). The material has excellent rheological properrties and was tailored to be applied on slopes up to 5 %, without sacrificing the protective function and mechanical properties. The full section of the deck and footpaths of the 65 m span bridge over Soča river was cast in one step,

over two days for the full length. An original combination of UHPFRC with Controled Permability Formwork (CPF) membrane (ZEMDRAIN®) helped produce finished footpath surfaces ready to walk barefoot which was one of the challenges set by the owner. The specially tailored thyxotropic mix held the 5 % slope without difficulties. Figure 2 a) shows the bridge and Figure 2 b) shows the casting of the footpath with the application of the CPF membrane on the fresh UHPFRC surface.

a) b)

Fig. 2 a) bridge Log Čezsoški (nearby Bovec– Slovenia); b) Application of of a CPF membrane on the fresh UHPFRC of the footpath.

4 Conclusions

- An original concept using Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) for the rehabilitation of concrete structures has been presented and validated by means of six applications.
- This conceptual idea efficiently combines the outstanding protective and mechanical properties of UHPFRC with conventional structural concrete. The rehabilitated structures have significantly improved structural resistance and durability with sustainable materials.
- These full scale realisations under realistic site conditions demonstrate the potential of this concept and its applicability in various countries, with locally available components, in various challenging conditions of application (slopes of 5 % of the substrate).

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5 References

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