Innosuisse-cemsuisse Project: "Strengthening of bridges using a layer of UHPFRC reinforced with memory steel"

Innosuisse Project No.: 56234.1 IP-ENG

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Duration of the project April 2022 - March 2025

Objectives of the project

The goal of the present research project is to develop an efficient and economically feasible alternative to existing strengthening methods for bridges. The use of prestressing techniques for strengthening purposes has the advantage of providing a better performance under service loads. The innovative method consists in applying a top layer of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) reinforced with memory steel over the parent Reinforced Concrete (RC) structure. Besides being able to enhance the load-carrying capacity of the original structure, the novel approach can potentially reduce crack widths, uplift excessively deformed structural elements and reduce the stresses in the internal reinforcement.

Methodology and procedure

A cost-benefit analysis was initially performed in order to assess the efficiency of the proposed method which combines Fe-SMA reinforcing bars and UHPFRC.

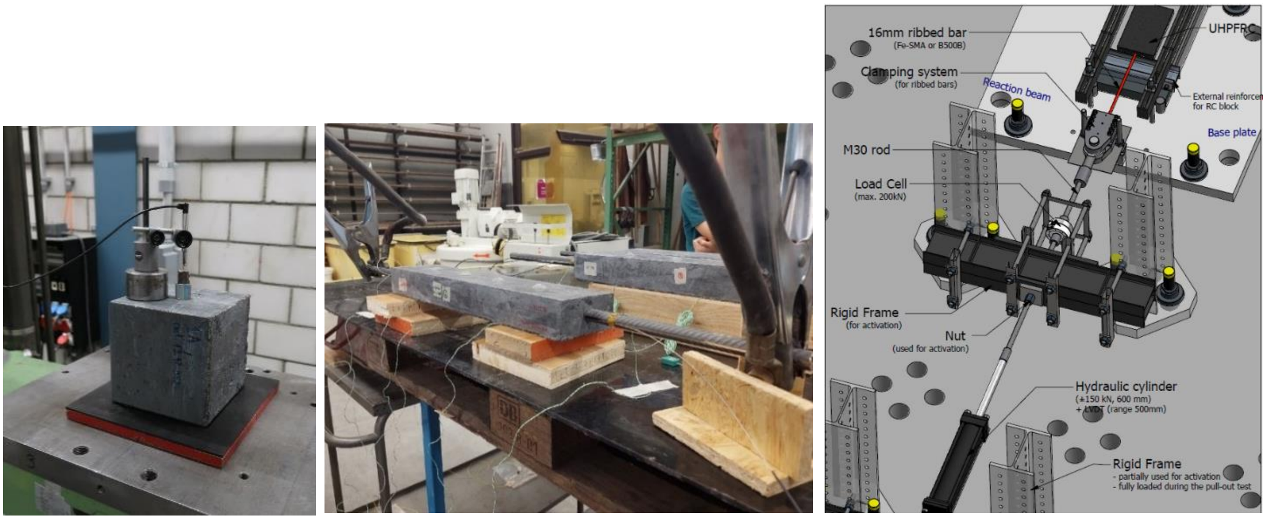
To study the novel technology, several experimental campaigns were performed in order to characterise the materials behaviour, and the bond behaviour between Fe-SMA and UHPFRC. The overall performance of the retrofitting method will be investigated in upcoming large-scale tests on cantilever slabs. High resolution technologies that use distributed fibre optical sensors (DFOS) are being implemented in the experiments to accurately measure the strains along fully embedded reinforcing bars, ultimately contributing to a better understanding of the bond interactions.

The experimental investigations will be followed by numerical and analytical studies, and, finally, structural design procedures will be developed and employed during calculations for a possible pilot application.

Findings for science, practice and the public

Following the cross-section analysis and the cost calculations, it was shown that even though the innovative strengthening method (UHPFRC + Fe-SMA) was roughly 15% more expensive than the conventional method (UHPFRC + B500), it can perform better under serviceability limit states (SLS) even though it uses smaller amounts of UHPFRC and of reinforcing steel.

To study the interaction behaviour between Fe-SMA bars and UHPFRC, a series of pull-out (PO) tests on reinforcing bars embedded in UHPFRC cubes, with short bonded lengths was carried out (Figure 1.a). Design parameters such as the type of steel, cover thickness and influence of heating were analysed. For all specimens, the peak bond strength was roughly in between 40-60 MPa. Even though a reduction of the peak strength of up to 20% could be observed for the specimens subjected to heating, code requirements are still guaranteed.



a) b) c)

Figure 1: Experimental test set-ups: a) short Pull-out tests; b) Activation tests on R-UHPFRC bars; c) long Pull-out tests.

Activation tests were performed for UHPFRC beams reinforced with 1m length Fe-SMA bars (Figure 1.b). These tests showed that it is not feasible to activate the memory steel bars when they are fully embedded in UHPFRC given that a great amount of energy is being used to heat the UHPFRC matrix, ultimately resulting in long heating times and premature cracks that spread longitudinally along the UHPFRC surface. The latter is explained by the high thermal conductivity coefficient of UHPFRC. Following these recent findings, the anchorage approach is recommended: first the Fe-SMA bars is placed in position and anchored at both ends with UHPFRC; then, after curing, the bars are heated with a direct heating source (or with resistive heating; and finally, the remaining surface in between the two anchorages is casted.

To further study the bond-slip behaviour between UHPFRC and Fe-SMA, a sequence of PO tests with longer embedment lengths - 40 cm - was performed (Figure 1.c). Several design parameters

were investigated, such as the bar material, the activation process, the layer thickness, the orientation of the steel fibres within the UHPFRC matrix and its curing time. During activation, the maximum prestress (recovery stress) obtained in the Fe-SMA bar amounts to 219 MPa.

Following these studies, a curing time of at least 4 days is recommended in order to ensure safety. A combined pull-out failure with concrete splitting at the surface was observed in all the specimens with memory-steel. The orientation of the steel fibres within the UHPFRC matrix highly influenced the way the cracks propagated at the UHPFRC surface, although it did not impact the ultimate PO failure load. A localised bar failure (necking) was obtained for the specimens using B500B steel bars.

Significance for research and practice: innovation

The use of prestressed strengthening techniques can be, in certain cases, the only alternative to demolishing and rebuilding an existing structure given the possibility to partially recover cracks on deteriorated elements or to uplift structural components that exhibit excessive deformations. The presented strengthening method has a significant interest as there are currently no prestressed strengthening alternatives for increasing the load bearing capacity of bridge decks under negative bending moments.

At this stage, the estimated cost for the innovative strengthening method (UHPFRC + Fe-SMA) was roughly 15% higher than the conventional method (UHPFRC + B500B). Notwithstanding, even if at the present moment, the innovative method is more expensive than current methods, it was demonstrated that it has a reduced ecological impact as the amounts of materials were reduced while still providing a better performance in terms of serviceability limit states (SLS) and further reducing the stresses on the internal steel. Additionally, it is foreseen that, with the increasing number of potential applications for memory steel, the prices of this smart material will decrease. Following the strengthening operations, maintenance costs are also expected to reduce since no chloride intrusion should be possible.