Concrete Slab Strengthening with CFRP Textile Reinforced Shotcrete

Daia ZWICKY
Professor, PhD, MSc (ETH)
University of Applied
Sciences Western Switzerland
daia.zwicky@hefr.ch

Daia Zwicky, born 1971, is currently vice-chair of WC4 “Conservation of Structures” and chair of the Swiss National Group of IABSE. His research interests cover modeling of structural materials, hybrid structural elements, and structural analysis and strengthening of existing structures.

Summary

This paper reports on a new strengthening system for concrete elements, being composed of carbon-fiber reinforced polymer fabrics (CFRP fabrics) embedded in shotcrete. The strengthening system was evaluated in a test series on full-scale single span slab strips of 6 m length, on a non-strengthened reference specimen and two slab strips with different strengthening ratios. The paper discusses the test results with regard to serviceability limit state (flexural stiffness, crack widths, and admissible loads for given deflection limits), and to ultimate limit state (strengthening ratio, behavior at rupture, post-peak bearing capacity, and ductility). It concludes with some analytical considerations on the structural behavior and bearing capacity of the new strengthening system.

Keywords: strengthening, reinforced concrete, slab, textile reinforcement, carbon-fiber reinforced polymer (CFRP), shotcrete, full-scale tests, SLS, ULS, bending, anchorage.

Introduction

Strengthening of existing structural elements in reinforced concrete with textile-reinforced concrete (TRC) is a relatively new technique. In comparison to strengthening with fiber-reinforced laminates glued with epoxy which have become state-of-the-art, TRC strengthening techniques have several advantages that are discussed in more detail in the full paper.

Full-scale tests on slab strips strengthened with TRC system “ARMO”

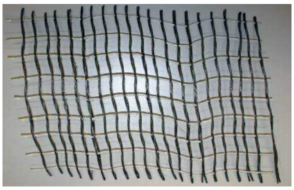

Fig. 1 CFRP fabric.

Full-scale bending tests up to failure were carried out on single-span reinforced concrete slab strips with a span of $L = 6$ m and a cross-section of 85 cm width and 22 cm height (slenderness 27.3), being provided with material qualities and reinforcement ratios as they are typically encountered in practice. A non-strengthened specimen served as reference for two further slab strips which were strengthened with one and two layers of uniaxial CFRP fabrics (Fig. 1) embedded in shotcrete. The material qualities and the test set-up are described in more detail in the full paper.

Structural behavior at serviceability limit state (SLS)

Fig. 2 shows the deformation behavior up to failure of the tested specimens under applied jack forces. The form of the deflection curves indicates that the textile reinforcements only absorb forces with progressive crack formation. This can be attributed, on the one hand, to an initially required straightening of the passively applied CFRP fabrics. On the other, the bond between textile reinforcement and shotcrete is rather poor, leading to a structural behavior of the fabrics that is closer to unbonded than to perfectly bonded reinforcement.

The full paper also provides information on SLS loads for usual deflection criteria as well as on the impact of repeated loading on bond of the CFRP fabrics to the surrounding shotcrete.

https://doi.org/10.2749/222137813806474345

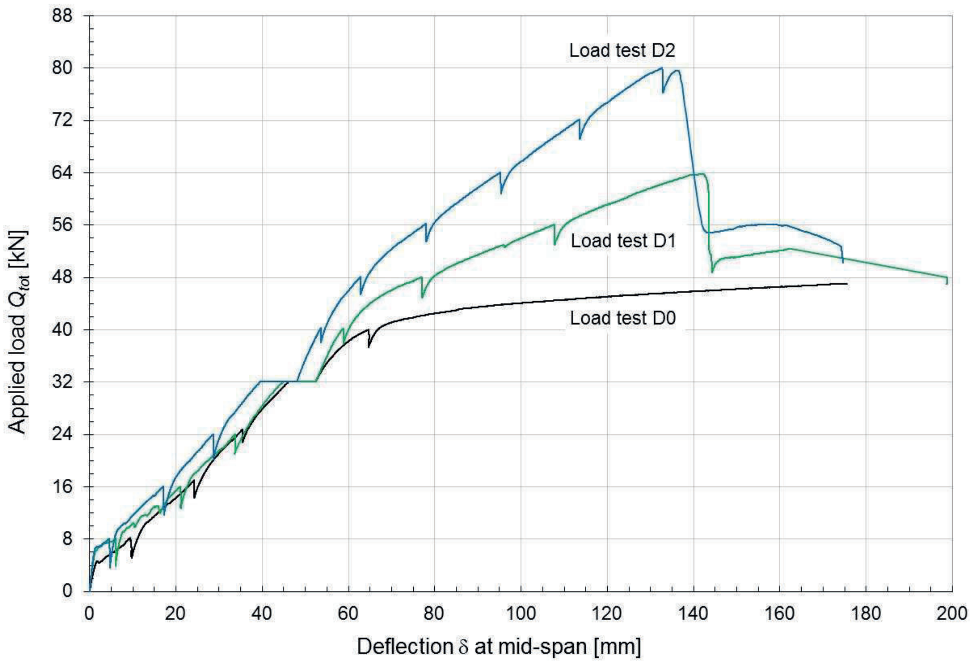

Fig. 2 Load-deflection curves for all tested slab specimens (load cycles at 8 kN hidden).

Behavior at ultimate limit state (ULS)

Yielding of the internal steel reinforcement essentially marks the start of effective load-bearing of the textile reinforcement, as it is also the case for externally bonded reinforcement. Consequently, TRC strengthening only contributes to ultimate resistance and not to serviceability properties.

Considerable degrees of strengthening of approx. 35% per fabric layer could be attained in the tests, being associated with a ductility reduction of 20 to 30%. The sudden loss in load-bearing capacity of the strengthened specimens (Fig. 2) can be attributed to anchorage pull-out failure at the ends of the TRC layers, not allowing for full exploitation of the CFRP tensile strength. Further tests for determining the anchorage resistance and associated bond lengths of the CFRP fabrics have already been performed and are currently evaluated for developing a design approach. None of the specimens showed rupture of the internal steel reinforcement or the textile reinforcement.

The full paper provides further evaluation of the test results with regard to loads at steel yielding, behavior of the specimens at rupture, post-peak bearing capacity, available ductility, recorded crack patterns and strains at ultimate.

The contribution concludes with the application of different analytical approaches for determining the CFRP fabrics stresses at ultimate and at yielding. It can be shown that the assumption of rigid (or at least sufficient) bond is not justified for the textile reinforcement investigated here. They should rather be considered as unbonded tension ties anchored at the beam's ends, in analogy to external prestressing, thus analyzing global deformations of the structure instead of cross-sectional strains. Reaching nominal ULS can be assumed at a maximum deflection of approx. $w_R = L/40$, but the associated strain in the CFRP fabrics should be reduced by a resistance factor of approx. 1.3.

Acknowledgements

The experimental study was performed under the guidance of Prof. Dr. René Suter who also provided the author of this paper with the results. This is highly acknowledged.