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Shear Strengthening of Prestressed Concrete Beams with UHPFRC – A Numerical Study

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1 Research description

Research relevance

The growing need for strengthening of concrete structures to improve their structural performance challenges engineers to come up with a strengthening technique that is most effective, economical and such that out-of-use periods of these structures are minimized. The use of novel cement-based materials such as Ultra High Performance Fibre Reinforced Concrete (UHPFRC) might be promising in this respect due to its exceptional material properties, in particular, strain-hardening behaviour in tension, high compressive strength, excellent durability and compatibility with existing concrete. UHPFRC, which can be applied either as cast-in situ overlay or as prefabricated laminate, might lead to an effective and easily applicable strengthening solution.

Research approach

In order to investigate the effectiveness of using UHPFRC in shear strengthening of prestressed concrete elements, a numerical study was performed with ATENA FEM-software [1]. The post-tensioned T-girders of the Helperzoom bridge, Groningen, the Netherlands were chosen as reference case for this study. First, the reference beam (T-R0), without strengthening, was modelled. The beam was subjected to 3-point flexural testing such to determine its shear capacity. Simulated results of the reference beam were verified with experimentally obtained results from the literature in which similar girders were tested. Second, a detailed numerical study was performed to understand the shear behaviour of the reference beam. The contributions of shear reinforcement and prestressing strands, active in the critical shear region, to the shear capacity and the final failure mode were investigated through performing a number of simulations on imaginary beams in which the amount of shear reinforcement and prestressing strands was reduced compared to the reference beam (samples labelled as T-R1, T-R2 and TR-3). Shear capacities for these beams were also verified by Huber's analytical model [2]. Finally, the effect of strengthening by applying perfectly bonded layers of UHPFRC at both sides of the web was investigated for the reference and imaginary beams (Fig. 1).

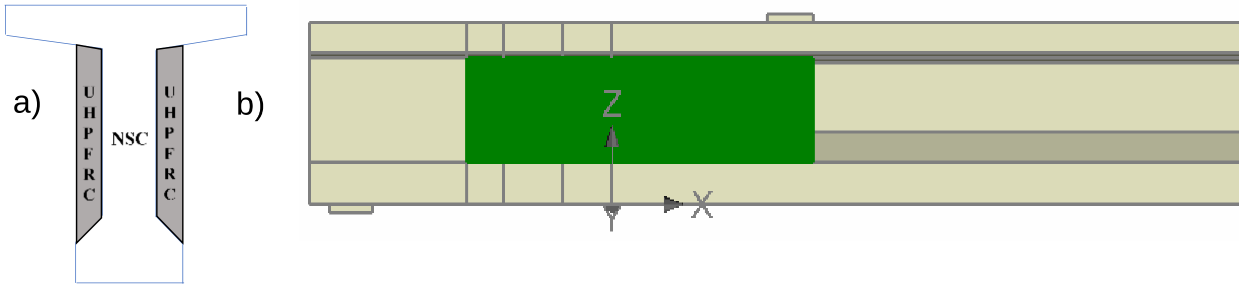

Figure 1: Configuration for strengthening a T-beam (a) cross-section & (b) part of the span (NSC=Normal Strength Concrete).

2 Numerical results obtained with ATENA

In the following, the outcomes of numerical simulations are compared for reference beams (R-series) with strengthed versions of the reference beams (U-series). The T-beams were strengthened with the UHPFRC composite on both sides of the web in the U-series. Perfect bond is assumed between the beam and the UHPFRC composite. The composite is added in the shear span of the beam, i.e., from 0.96 m from the left-hand support till the loading point. The direct tensile behavior of UHPFRC was assumed with a tensile strength f_t of 7.0 MPa, an ultimate tensile capacity f_{ut} of 8.0 MPa (at a strain of 2.5 promille) and a maximum strain of 3 promille.

The numerically predicted shear capacity of the reference beams (without strengthening) was found to be close to that calculated with the Flexural Shear Crack Model [2]. Figure 2 compares the load-deflection curves for reference and strengthened beams T-R0 (Fig. 2a) and T-R3 (Fig. 2b). TR-0 beams comprise of original reinforcement configuration, whereas in T-R3 beams, shear reinforcement and inclined prestressing cables crossing the shear span are removed. In T-R0 beam, although a critical shear crack opens at a load of around 1300 kN, this crack does not develop into failure mechanics, but the beam ultimately fails in shear compression failure at the load of around 1900 kN. On the other hand, the failure mode of the reference beam T-R3 is shear tension failure. It is found that the strengthening enabled a flexural failure for all simulated cases. However, the effectiveness of the strengthening varies, being the largest for the beams with the lowest initial shear capacity. The change in configuration of adding the UHPFRC - bonding UHPFRC to only the web region of the T-beam - showed the same effect as bonding UHPFRC to both the flange and web regions of the T-beam. The study also showed that the strain-hardening property of the UHPFRC material can be effective to prevent brittle shear failure and to increase the ultimate load-bearing capacity.

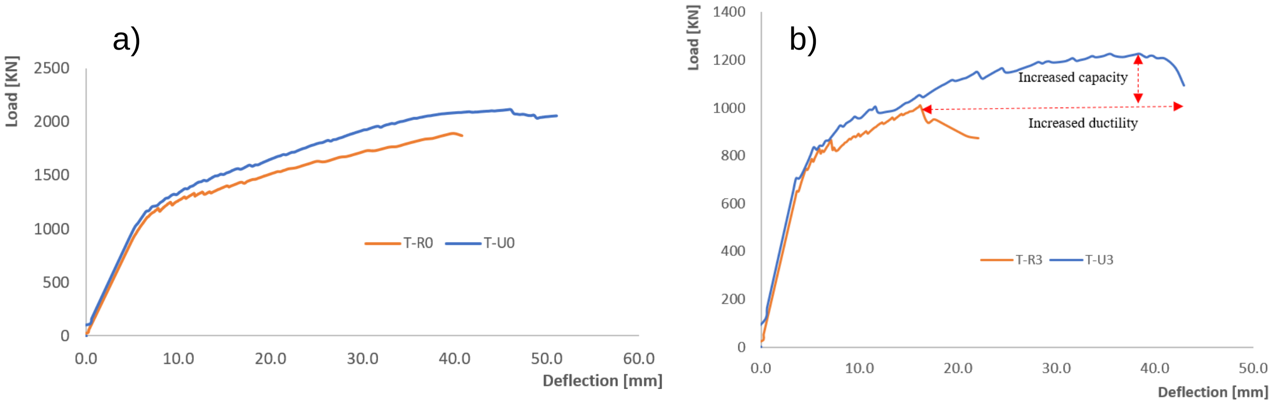

Figure 2: Comparison of load-deflection curves for reference beams and for the same beams, which were strengthened with UHPFRC (a) T-R0 vs T-U0, (b) T-R3 vs T-U3.

3 Conclusions

Although these results still need to be further verified by experimental testing, they confirm the potential of UHPFRC strengthening, but also highlight the need for thorough and accurate assessment of the structural behaviour and capacity of the existing structure prior to considering any strengthening method.

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