Composite Materials for the Sustainable Refurbishment of Bridges

The European project SUREBridge is developing a new technique for the structural strengthening of road bridges. Its effectiveness has been demonstrated through finite element analyses and full-scale laboratory tests

SURE BRIDGE
Sustainable Refurbishment of Existing Bridges

The SUREBridge Project Consortium is composed by:

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Introduction

Providing an innovative and sustainable solution for the refurbishment of road bridges and users safety: this is the aim of the European research project SUREBridge (Sustainable Refurbishment of Existing Bridges), co-financed by the European Commission through the ERA-NET Infravation 2014 Call.

Due to the expected increase in the traffic volume, existing bridges will be subjected to more severe actions in the near future. Consequently, the need to refurbish these infrastructures, often structurally deficient and obsolete, will increase dramatically. At present, construction and maintenance activities relating to bridges imply costly and time-consuming procedures, with a negative impact on traffic flow and welfare in wider terms. In addition to disturbance, disruption, and pollution, other main challenges are the inefficient use of resources, i.e. materials, energy, waste management, and recycling. Thus, the target of the SUREBridge project is to increase the load-carrying capacity of concrete and steel-concrete bridges to the desired level, exploiting the remaining capacity of the superstructure and preserving the structural elements of the deck. This is achieved by using tailor-made glass fibre-reinforced polymer (GFRP) panels, installed on top of the existing concrete slab, and carbon fibre-reinforced polymer (CFRP) laminates, applied to the bottom side of the girders. Such laminates are pre-stressed by using an innovative technique, which avoids stress peaks in the CFRP-concrete interface, thus preventing early delamination. Furthermore, the GFRP panels can be manufactured of the same width or wider than the existing deck, enabling to widen the road section if needed.

A case study bridge

To prove the effectiveness and feasibility of the proposed technique for real-life applications, a bridge located in the municipality of San Miniato (Tuscany, Italy) was selected as a case study (Figure 1). Dynamic modal and linear static analyses were carried out with the commercial software Straus7 to assess the load-carrying capacity before and after the widening and strengthening intervention provided for the bridge (Figure 2). The increment in the load-carrying capacity obtained with the SUREBridge solution was evaluated with a simplified calculation datasheet. It was demonstrated that the combined use of GFRP panels and CFRP laminates enables to bring the bridge load-carrying capacity from 51% (current conditions) up to the 100% of the traffic loads prescribed by the current Italian regulations.

Figure 1 - The San Miniato bridge - Current conditions

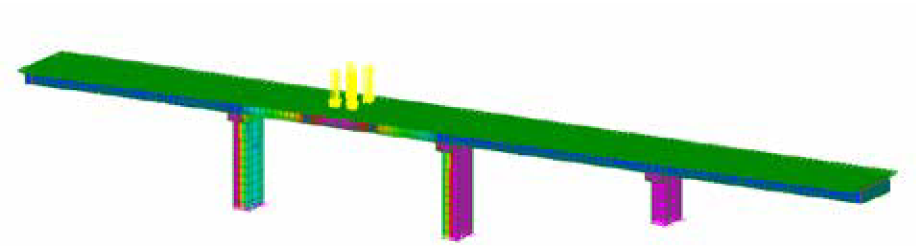

Figure 2 - The San Miniato bridge – Finite element model

Laboratory tests on prototype beams

A clear demonstration of the high strengthening capacity of the proposed technique was given through full-scale tests on T-shaped cross-section prototype beams. These tests are representative of the conditions often occurring in real concrete bridges – as the San Miniato bridge – since the T-shaped cross section acts as a simplified version of a longitudinal girder with an upper collaborating slab. In August 2017, four 6-m long prototype beams (Figure 3) were tested under four-point bending in the laboratory of the Structural Engineering Division of the Department of Civil and Environmental Engineering at Chalmers University of Technology (CTH). Earlier in July 2017, theoretical predictions of the structural behaviour of such specimens were carried out by means of finite element non-linear analyses at the University of Pisa. In particular, a fibre-modelling approach was used, whereas the tested beam is represented as the assemblage of small BEAM elements representing ideal longitudinal fibres.

Two of the four prototype beams – the reference reinforced concrete beam (specimen 1) and prototype beam strengthened with longitudinal GFRP panels and pre-stressed CFRP laminate (specimen 3) – were modelled with the software Straus7 using the above-mentioned approach (Figure 4). Such models were accurately calibrated referring to the experimental results obtained during some preliminary laboratory tests on rectangular cross-section beams, conducted at CTH in October 2016.

Going into details of the finite element models, the cross section of the beams was subdivided into three different parts – unconfined concrete, confined concrete, and steel reinforcements – each corresponding to a different material with specific mechanical properties and stress-strain curves.

Figure 3 - Prototype beam strengthened with the SUREBridge technique and tested in the laboratory

The modified model by Kent and Park (1971) was used to define the stress-strain curves for confined and unconfined concrete in compression. Besides, the stress-strain curves both for confined and unconfined concrete in tension were extrapolated from the values of the elastic modulus and mean tensile strength. An elastic-plastic stress-strain curve was chosen for the steel reinforcements, while an elastic-brittle stress-strain curve was considered for the CFRP laminates of the strengthened prototype beam. Such elements were connected to the bottom of the concrete beam using an epoxy adhesive layer, schematised as a continuous distribution of springs and introduced into the finite element model by using CONNECTION elements. The equivalent shear and axial stiffness of such elements were computed based on the thickness of the adhesive layer and the values of its elastic moduli given by the producer. Furthermore, the pre-stress distribution on the CFRP laminates was obtained considering the maximum pre-stressing value and the typical length needed to introduce such pre-stressing force with the set-up developed at CTH. The GFRP panels, installed on the top of the strengthened beam with the webs oriented in the longitudinal direction, were modelled with LAMINATE elements. In particular, the different layers of the panel have been defined as

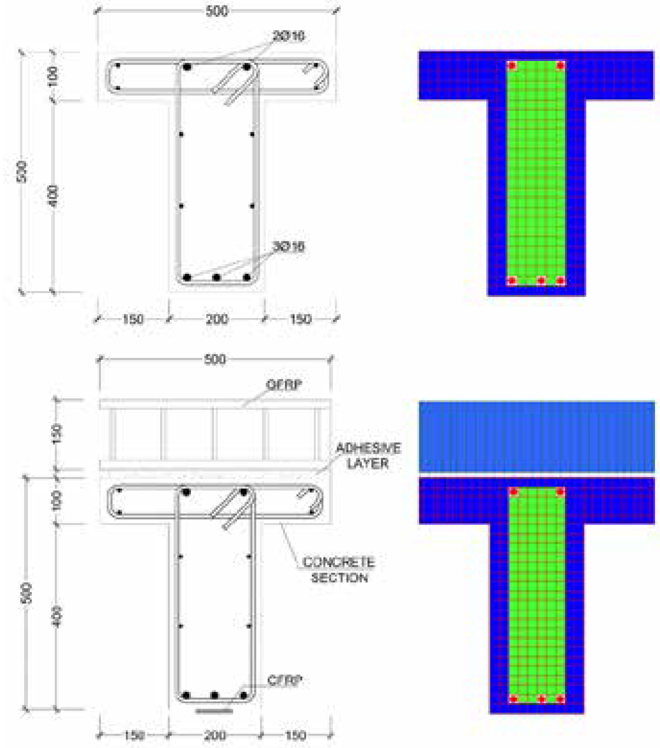

Figure 4 - Cross sections and finite element models of the prototype beams (specimens 1 and 3)

individual PLY elements, then combined into a LAMINATE element representing the panel. An equivalent internal core replaces the actual spatial distribution of the webs in order to simplify the model and reduce computational time. Such modelling approach was validated first by separate finite element analyses on single GFRP panels, showing a good agreement between the accurate and simplified core models. In addition, the same assumption made for the CFRP-concrete bonding were also made for the GFRP-concrete bonding.

The non-linear analysis of the models was developed with progressive and appropriate load increments to obtain the theoretical load-deflection curves, which were compared to the experimental curves once the laboratory tests were performed (Figure 5). A very good matching between the theoretical predictions and experimental results was obtained and, in this respect, it should be stressed that the finite element models were not calibrated against the experimental results – conducted one month later than the delivery of the models – for the simulated tests.

Conclusions

"We are confident to obtain even better agreement with experimental results, once the output of mechanical tests on material samples will be available" states Prof. Paolo S. Valvo, Scientific Responsible person of the University of Pisa working group. Such tests are currently (October – November 2017) being carried out at the Chalmers University of Technology and the finite element models will be updated accordingly. "Bridges are critical transport infrastructures, fundamental for the performance of the road transport network. The refurbishment of the existing obsolete structures is crucial for the users' safety" concludes Prof. Valvo.
The technique developed within the SUREBridge project can represent a sustainable and effective solution for the refurbishment of concrete and steel-concrete bridge. The key role for the effectiveness of the proposed technique is played by the combined use of GFRP panels, installed on the top of the existing deck, and CFRP pre-stressed laminates applied to the bottom side of the longitudinal girders. This was demonstrated through the structural analysis of the case study bridge, where the separate use of CFRP laminates and GFRP panels enabled to reach the desired load-carrying capacity, but with major problems such as high thickness of the panels or high number of laminates.

The excellent strengthening capacity of the CFRP-GFRP combined use was further demonstrated through laboratory tests on full-scale prototype beams, where the observed structural response was successfully predicted based on finite element non-linear analysis.

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For further information: www.surebridge.eu

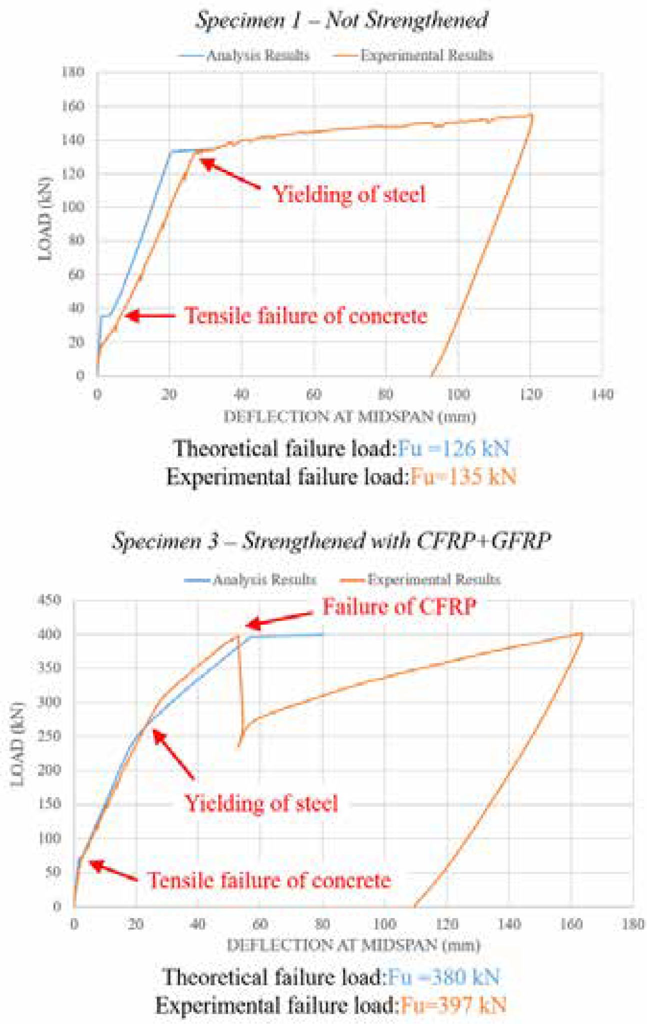

Figure 5 - Comparison between the theoretical and experimental load-deflection curves