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Influence of the asphalt pavement on the short-term static strength and long-term behaviour of RC slabs strengthened with externally bonded CFRP strips

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ABSTRACT

Lateral cantilevers of Reinforced Concrete (RC) box-girder bridges might have a lack of negative bending resistance in cross-direction due to the increase of traffic loads or the degradation along the time of the material properties. Externally Bonded (EB) Carbon Fiber Reinforced Polymer (CFRP) strips on the top side of these bridge slabs are a possible strengthening technique for such purpose. The paper presents a study regarding the short- and long-term behaviour of such reinforcements where the specific case of a lateral cantilever element is investigated. Strengthening of negative bending moments on the upper deck side implicates the exposure of the composite reinforcement to both short- and long-term elevated temperature scenarios. During the construction phase, the application of warm mastic asphalt induces elevated peak temperatures in the epoxy resin of about 80 °C with a subsequent slow cooling phase over several hours. In this investigation, the temperature evolution on several locations was measured. Then, the short-term residual bond strength of the strengthened system after such an exposure is checked with both lap-shear and large-scale tests. The long-term behaviour with the seasonal temperature fluctuation is another concern. For this purpose, a cantilever slab with a real asphalt layer under sustained load was installed and continuously monitored in time over one year.

1. Introduction

Lateral cantilevers of RC box-girder bridges might have a lack of negative bending resistance in cross-direction due to the increase of traffic loads or the degradation of the material properties [1]. EB CFRP strips glued on the top side of these bridge slabs could be used as a strengthening technique to increase the load bearing capacity in transverse direction of such elements as Fig. 1 shows [2].

EB CFRP strips used to improve the transverse behaviour of RC box-girder bridges can reach elevated temperatures during the construction process or even later due to the sun radiation. These elevated temperature scenarios could limit the application of such reinforcement systems due to the degradation of the mechanical properties in the epoxy adhesives [3]. In order to define the temperature scenarios where these reinforcements can be used, the producer should indicate in the epoxy technical data sheet the glass transition temperature (T_g) of the resin, namely, the temperature level above which the polymer starts to soften [4]. When the environment temperature is close or exceeds T_g, the epoxy adhesive starts to lose its ability to transferred shear stresses between the CFRP strip and the concrete surface due to the decrease in the epoxy elastic modulus [5]. Besides, an increase in deflections could be expected at this temperature level due to creep of the epoxy adhesive at elevated temperature [6–8]. From a design viewpoint, it is necessary to define the maximum temperature reached during service in order to verify the range of application of these adhesives.

In spite of the mentioned problems, several experimental studies have proved that elevated temperature levels during a short period of time increase T_g and improve the mechanical properties of the epoxy resins [9,10]. This post-curing at elevated temperature accelerates the development of the mechanical properties of such adhesives. When more thermal energy is supplied to the system curing reactions can take place more frequently and a higher degree of cross-linking of the polymer chains can occur [11]. However, the concrete substrate is prone to damage due to the formation of microcracks at elevated temperature and this degradation might influence the short- and long-term behaviour of RC elements strengthened with EB CFRP strips.

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Nomenclature

A_f	strip area
b_f	strip width
E_{asp}	elastic modulus of the mastic asphalt
E_f	elastic modulus of the strip
F	applied force in the beam
f_c	concrete compressive strength at 28 days
f_{ct}	concrete tensile strength at 28 days
$f_{ct,fl}$	flexural concrete tensile strength at 28 days
F_f	maximum strip force
L	cantilever length
M_{cr}	cracking moment of the strengthened section
M_{max}	maximum bending moment in the cantilever beam
s_f	strip slip
T_a	temperature in the epoxy adhesive
T_{asp}	asphalt temperature
T_g	glass transition temperature of the epoxy adhesive
t_f	strip thickness
u_f	strip displacement in the horizontal direction
X	horizontal displacements measured with Image Correlation System
X_0	horizontal displacement of the slab at the support due to the body movement
X_{corr}	horizontal displacements corrected
X_{meas}	horizontal displacements measured with Image Correlation System
v	tip displacement of the cantilever slabs
Z	vertical displacements measured with Image Correlation System
ε_f	strip strain
$\varepsilon_{f,max}$	maximum strip strain
$\varepsilon_{f,exp}$	experimental value of the maximum strip strain
$\varepsilon_{f,the}$	theoretical value of the maximum strip strain
ΔX	pseudo-displacement produced due to large deformations
θ	angle of rotation of the slab
σ_f	tensile stress in the strip
τ	shear stress in the interface strip-concrete

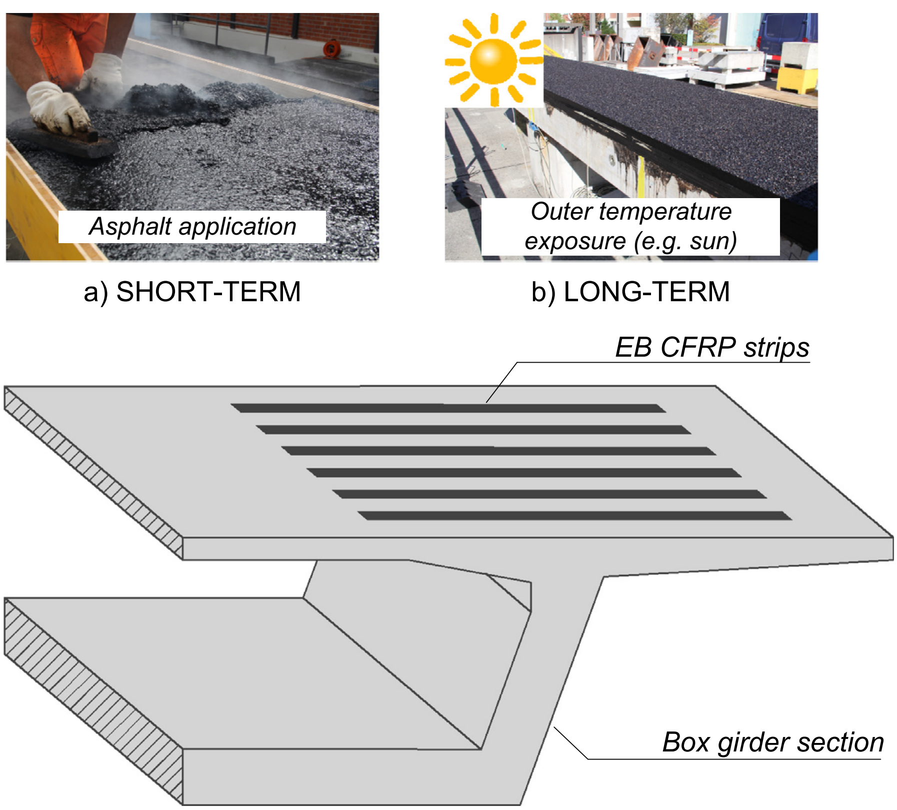

Fig. 1. CFRP strip strengthening in cross-direction in a reinforced concrete box-girder bridge and elevated temperature scenarios.

This research aims to study the structural behaviour of CFRP-strengthened RC structures when elevated temperatures from asphalt application and sun exposure occur. In this paper, the effect of warm mastic asphalt at construction stage and temperature variations in time are studied in detail. Several tests for studying the effective temperature development in the epoxy adhesive during the asphalt application, the residual strength after the application as well as the long-term behaviour under sustained load have been performed and are presented hereafter.

The investigation is divided in two main parts. Firstly, the temperature evolution on several locations was measured during the application of the mastic asphalt layer. Then, the short-term residual bond strength of the strengthened system after such an exposure was checked with both lap-shear and large-scale tests. To study the long-term behaviour of these elements due to the seasonal temperature fluctuation, a cantilever slab with a real asphalt layer under sustained load was installed and continuously monitored in time over one year.