Reliability-Based Design Optimization of a CFRP Bridge

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Summary

In this paper, a new all-composite fiber reinforced polymer (FRP) bridge typology is introduced. The structural system is composed by 4 families of 5 carbon fiber reinforced polymer (CFRP) symmetrically disposed straps, connected to 4 corner-supports and combined with a central CFRP strap. A glass fiber-reinforced polymer (GFRP) deck rests on top of several GFRP variable-section beams, which transfer the loads from the deck to the main net of CFRP laminates. Every structural component of the bridge is bonded by an adhesive resin to the others in contact with it. The bridge is simply-supported at the four CFRP strap family supports and at the extreme GFRP beams that support the deck plate. This way, the span of the bridge is equal to its total length
The new-concept of bridge was studied by a finite element (FE) model of the structure. This FE model was further used to adjust a surrogate model of the bridge that was subsequently used for the optimization algorithm. A damage evolution model was implemented in the optimization algorithm to consider the stiffness reduction due to fatigue damage during the lifetime. Finally, the optimum bridge was analysed, checking that it fulfils the structural requirements stated in the design code EC3-2.

The results of this work is not only a new optimized bridge concept, but also a scientific design approach that allows us to conceive rational structural designs made with new materials.

Keywords: bridge, carbon fiber, design, optimization, reliability, surrogate model

1. Introduction

Composite materials are gaining importance in civil engineering applications, such as bridges, due to their high stiffness and strength in relation to their low weight. The advantage of using FRP composites for civil engineering structures relies not only on their mechanical efficiency, but also on their ability to be adapted to hostile environmental conditions. However, the long-term behaviour of composites under fatigue and damage conditions is still partially understood. Nevertheless, the rampant increase of applications of uncertainty quantification (UQ) to engineering structures together with the know-how that is gaining the composite industry, may allow new concepts of carbon fiber-reinforced polymer (CFRP) bridges by considering the uncertainties in the design.

Design codes typically circumvent the UQ analysis by imposing highly-enough safety factors that ultimately lead to a more expensive design. However, uncertainty turns essential for designing of composite structures since the requirements for the serviceability are high. To the last, it is added that numerous degradation processes (a priori uncertain) arise in the composite material from the

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