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A modified Duvaut-Lions zero-thickness interface model for simulating the rate-dependent bond behavior of FRP-concrete joints

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Abstract

This paper proposes a model aimed at simulating the strain-rate effect in Fiber Reinforced Polymer (FRP) strips glued to concrete. More specifically, the loading rate-dependent bond mechanisms are evaluated by extending a classical overstress viscoplastic approach, available in the literature, generally referred to as Duvaut-Lions' approach. The model is formulated within the general theoretical framework of fracture mechanics under the assumption that debonding occurs as a pure mode II cracking process. Zero-thickness interface elements were employed for implementing the aforementioned FRP-to-concrete joint model. From the conceptual viewpoint, the model is used in an incremental analysis and the debonding phenomenon is simulated as a propagating fracture whose local residual stress is described by the decreasing branch of a bond-slip law assumed "a priori". The mechanical soundness of the proposed model is demonstrated by the very good agreement between some experimental results, taken from the scientific literature, and the corresponding numerical predictions at significantly diverse loading rates ranging from 0.07 to 70 mm/s.

Keywords: FRP; Pull-off; Visco-plasticity; Extended Duvaut-Lions; Fracture-based model.

1. Introduction

Fiber-Reinforced Polymers (FRPs) are widely employed both as internal reinforcement of new reinforced concrete (RC) constructions and external retrofitting of existing ones [1]. The externally bonding reinforcement (EBR) [2] and near-surface mounted (NSM) [3] techniques are the most employed solutions to strengthen concrete structures, mainly in bending and shear. In both cases, yet through different local mechanisms, bond between FRP strip and concrete substrate generally controls the structural response of FRP-to-concrete joints. Therefore, besides the identification of accurate bond-slip relationships, which has been duly studied in the past years [4, 5, 6], several critical aspects are currently under investigation.

The integrity of the FRP-to-concrete interface in aggressive outdoor environments is one of those aspects. Deterioration modeling, non-destructive methods for field evaluation and emerging developments in design, specifications and product approval have been reviewed and discussed in a recent paper [7]. Moreover, the performance under fire exposure of FRP-strengthened RC structural members is another issue of current relevance in the scientific literature. The mechanical behavior at high temperature of the constituent materials of FRPs and how their bond to concrete is affected when heated have been investigated [8]. Furthermore, the consequences of blast and impact actions on structures has attracted the attention of the technical and scientific communities. Experimental evidences show that FRP can be also used as an excellent material to improve the resistance of concrete structures under these actions [9, 10].

Bonding of a FRP plate to the tension face of a beam is one of the most common flexural strengthening method employed. Plenty of studies have been carried out in the last decades with the special aim to investigate and simulate the behavior of FRP-strengthened RC beams [11, 12]. Moreover, national and international guidelines have adopted some of those models leading to a wider spectrum of possible applications for FRP composites in structural engineering [13, 14]. Nevertheless, among the various aspects regarding the mechanical behavior of FRP-strengthened concrete members, simulating the bond interaction between FRP strips and concrete substrate has been recognized as a major and key issue in this field. Complex phenomena, such as failure induced by cyclic loading or fire exposure, have been recently taken into account in order to numerically simulate these events in FRP-to-concrete joints. For instance, Martinelli and Caggiano [15] formulated a model capable to reproduce the (low cyclic) fatigue behavior of FRP strips externally bonded to concrete by considering both bi-linear and linear-exponential bond-slip laws (both based on Fracture Me-