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Modelling the FRP-concrete delamination by means of an exponential softening law

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ABSTRACT

Among rehabilitation strategies, bonding of Fibre Reinforced Polymers (FRP) plates is becoming more and more popular, especially for what concerns concrete structures. The performance of the interface between FRP and concrete is one of the key factors affecting the behaviour of the strengthened structure. Up to now, closed-form analytical solutions exist only for the local bond–slip law with linear softening. The aim of the present paper is to show that analytical solutions can be achieved also assuming an exponential decaying softening law. Accordingly, the expressions for the interfacial shear stress distribution and the load–displacement response are derived for the different loading stages. A full parametric analysis of the problem has been performed, highlighting the size effect on the structural behaviour as well as the effects of the bond length, of the FRP stiffness and of the interface cohesive law. A comparison with other analytical models as well as with experimental data available in the literature concludes the paper.
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1. Introduction

Bonding of FRP has emerged as a wide-spread method for retrofitting existing concrete structures. In this technique, the performance of the FRP-to-concrete interface is of primary importance. The failure mode of FRP-reinforced beams is often directly related to the debonding of the FRP plate from the substrate. The debonding of the plate may take place either from the edge of the FRP strip or from an intermediate flexural crack (for a review, see e.g. [1]). The former failure mode is named *edge debonding*, whereas the latter is usually referred to as *intermediate crack-induced debonding* (IC-debonding, Fig. 1).

In the case of IC-debonding failure [2], the stress state is, up to some extent, similar to that of a single or double pull–push shear test (Fig. 2), where one or two FRP plates are bonded to a concrete block and subjected to a tensile load. Because of its relative simplicity, several experiments as well as theoretical analyses have been concerned with such a test geometry. Experiments [3] show that the principal failure mode is concrete failure under shear, leading to a main crack running a few millimetres beneath the concrete-to-adhesive interface. Thus, the maximum bearable load strongly depends on concrete mechanical properties.

Several models have been proposed to describe the pull–push shear test: among the others, we may cite Wu et al. [4], Yuan et al. [5], Leung and Yang [6] and references therein. However, an analytical solution for the complete debonding process is available in closed-form only for a local bond–slip law with linear softening (Yuan et al. [5], Leung and Tung [7]). The aim of the present paper is to provide an analytical solution for an exponentially decaying softening of the interfacial stress–displacement law. Up to now, the solution, in the case of a non-linear softening cohesive law, has been achieved only numerically (see, e.g., [8]). Finally, observe that, although the attention is focused on FRP-to-concrete bonded joints, the present analysis is applicable also to other kinds of reinforcement, e.g. steel plates.

2. Governing equations

In Fig. 2 the double and single pull–push shear test geometries are drawn. The first geometry (Fig. 2(a)) can be regarded as a kind of double lap joint. In such a joint, the adhesive layer is mainly subjected to shear deformations, so that mode II interfacial fracture is the expected failure mode. However, note that a rigorous elastic analysis of the problem shows that a mode I component is also present [9], but we will neglect such a contribution since it can be shown [10,11] that peeling stresses at the end of a double lap joint are negligible if the thickness of the outer adherends is small enough.

The single shear test is more common in experiments, since it is more easily feasible. Provided that a positioning frame preventing the concrete block from up-lifting is present (Fig. 2(b)), the stress–strain state in the double and single pull–push

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