Engineering Structures 33 (2011) 3715–3725

Contents lists available at SciVerse ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Modeling in-plane and out-of-plane displacement fields in pull-off tests on FRP strips

Enzo Martinelli [a,*], Christoph Czaderski [b], Masoud Motavalli [b]

[a] University of Salerno, Department of Civil Engineering, Fisciano, Italy
[b] EMPA, Structural Engineering Research Laboratory, Dübendorf, Switzerland

ARTICLE INFO

Article history:
Received 17 February 2011
Received in revised form
28 July 2011
Accepted 1 August 2011
Available online 3 September 2011

Keywords:
Concrete
FRP
Interface
Bond
Delamination
Fracture

ABSTRACT

The present paper deals with modeling FRP strips bonded to concrete blocks and tested in pull-off. The investigation starts from the experimental observations obtained by means of an optical image-correlation measurement system which is able to monitor the 3D displacement components of a fine mesh of points on the surface of both the FRP strip and concrete block. Thus, refined measurements of both in-plane and out-of-plane displacements of the FRP strips are available.

A brief overview of the key contributions available in the scientific literature on modeling the bond behavior of FRP strips glued to a concrete substrate is firstly proposed. Then, a novel model based on simulating the behavior of the FRP strip as a Bernoulli beam on a layer of springs is formulated. It is aimed at determining the 2D displacement field of the FRP strip during a pull-off test up to debonding which actually occurs in a mixed fracture mode. The model is firstly formulated within the linear range by assuming elastic behavior for the above mentioned springs. The nonlinear behavior due to the cracking of concrete beneath the adhesive interface is then introduced for simulating the above mentioned experimental results. In particular, a bilinear relationship is assumed between interface slips and shear stresses, as is generally accepted within the scientific literature. Furthermore, a damage model is considered for reducing the stiffness of the transverse springs and simulating the crack propagation at the adhesive–concrete interface. Although this is a simplified way of modeling the nonlinear behavior of concrete in shear/tension, it results in rather accurate simulations of the available experimental results. In fact, it can simulate accurately the overall behavior observed in three experimental tests on specimens characterized by significantly different mechanical properties of the strip. Since the model assumes a small set of mechanical parameters for describing the mechanical behavior of the adhesive FRP–concrete interface and results in a reasonable small set of equations, it can be easily employed for identifying the above mentioned mechanical behavior indirectly. Other numerical models already available in the scientific literature (especially those based on the theory of finite elements) for simulating the 2D displacement field in the debonding stage are generally based on much more equations and require a much higher computational effort which makes impractical their use in an indirect identification procedure like the one presented in this paper. In fact, one of the main results of this study consists in determining the distribution of normal (peeling) stresses throughout the adhesive-to-concrete interface. This stress component (Mode I) can neither be directly measured during the tests nor determined by the theoretical models usually adopted for simulating the fracturing behavior of FRP-to-concrete joints in the so-called fracture process in "mode II". Finally, it was found that the shear stresses are significantly higher than the peeling ones and control the crack propagation process.

1. Introduction

The use of fiber-reinforced polymers (FRP) is becoming more and more common as a possible technical solution for strengthening reinforced concrete (RC) members in bending, shear, and compression [1]. The issue of the bond between such materials and concrete is of key importance for the success of whichever strengthening intervention, especially in the case of members in bending [2]. Consequently, both experimental tests and refined numerical methods are needed for understanding the basic features of the interaction between FRP and concrete [3]. In particular, evaluating the stress distribution throughout the adhesive interface is the final aim of several studies already available in the scientific literature.

* Corresponding author. Tel.: +39 3394235874; fax: +39 089964098.
E-mail address: e.martinelli@unisa.it (E. Martinelli).

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.08.008