Engineering Structures 33 (2011) 827–842

Contents lists available at ScienceDirect

Engineering Structures

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

Unified analytical approach for determining shear capacity of RC beams strengthened with FRP

V. Colotti [a,*], R.N. Swamy [b]

[a] Department of Structural Engineering, University of Calabria, 87030 Rende (CS), Italy
[b] Department of Mechanical Engineering, University of Sheffield, UK

ARTICLE INFO

Article history:
Received 30 April 2010
Received in revised form
4 November 2010
Accepted 1 December 2010
Available online 3 January 2011

Keywords:
Beam
Failure
Fiber reinforced polymer
Reinforced Concrete
Shear strength
Strengthening

ABSTRACT

This paper presents a rational model to predict the ultimate load capacity of reinforced concrete (RC) beams strengthened by a combination of longitudinal and transverse fiber reinforced polymer (FRP) composite plates/sheets (flexure and shear strengthening system). The model is based on the truss analogy and the theory of plasticity and is opportunely refined in order to incorporate some critical aspects, such as variable angle crack, non-uniform FRP stress distribution over the shear crack, shear span/depth ratio. It is a general and unified model that allows consideration of all the main possible failure mechanisms of strengthened RC beams, related to flexural-shear interaction, shear web-crushing and pure flexural mechanisms. The model is validated against a large number of beam tests reported in the literature, involving a wide range of geometrical and mechanical characteristics. The numerical investigation shows a very satisfactory correlation between predicted and experimental data.

1. Introduction

A wide variety of reasons, ranging from ageing and environmentally induced degradation to poor initial construction and lack of maintenance, damages derived by accidental or natural causes, in addition to other problems related to the need to increase the service load to accommodate heavier loads, render more and more an increasing number of existing constructions structurally or functionally deficient. As a result, very large numbers of structures are in need of strengthening. Therefore, the development of effective, durable, inexpensive and unobtrusive rehabilitation techniques represents a formidable challenge facing the construction industry in the next years.

Bonding of steel plates or fiber reinforced polymer (FRP) composites with a suitable epoxy adhesive represents a repair and strengthening method that has gained acceptance all over the world in the last decade. Strengthening with externally bonded FRP reinforcement has been shown to be applicable to many types of reinforced concrete (RC) structures. Currently, the uses of external FRP reinforcement may be generally classified as axial (confining), flexural and shear strengthening. It has been shown through experimental and theoretical studies that externally bonded steel plates or FRP composites can be used to improve the performance of a flexural RC member. However, a critical review of the published literature shows that beams strengthened with FRP suffer from two major weaknesses, namely: (a) lack of ductility and (b) lack of adequate safety in shear. In particular, strengthening structures separately for flexure or shear can mask inherent structural weaknesses in ductility and shear, and can lead to premature failure. Furthermore, in analyzing strengthened RC beams it is common practice to carry out distinctly separate analysis for flexure and for shear. These steps comprise a sequence of interdependent analyses where one analysis is independent from the other. In addition, while the flexural mechanism can be reasonably predicted by models based on the simple Bernoulli flexure theory, when the shear and/or debonding mechanisms govern the response of a strengthened RC member, the problem of the correct prediction of ultimate strength is more complicated, due to the complexities involved with these mechanisms.

Extensive research studies [1–3] prove without a shadow of doubt that there is a close, synergistic interaction between flexural strengthening and shear strengthening and, therefore, strengthening of beams should not be seen as strengthening for flexure and/or strengthening for shear but as strengthening for flexure and shear. In fact, to preserve structural integrity and structural safety, a synergistic interaction between tensile strengthening and shear links is essential, since external shear links act compositely with external longitudinal reinforcement, with significant technical benefits,

* Corresponding author. Tel.: +39 0984 496923; fax: +39 0984 494045.
E-mail address: colotti@unical.it (V. Colotti).

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doi:10.1016/j.engstruct.2010.12.005