# Fiber Reinforced Polymer Confinement of Bridge Columns Suffering from Premature Bars' Buckling – Strength empirical model

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## Summary

A critical review of the anti-buckling strengthening design procedures of the bars of existing reinforced concrete (RC) columns through fiber reinforced polymer (FRP) confinement is presented. Furthermore, the results of a parametric analytical study, performed by the authors, using finite element method for old-type existing columns with optional steel bars' buckling under compression are utilized in order to propose an upgraded empirical strength model. The parametric study involved column models constructed with three-dimensional finite elements for concrete and steel incorporating plasticity theory and laminas for FRP jacket elastic response. After elaboration of the parametric finite element analyses of characteristic RC columns, the effect of the existing bars' yield strength on the behaviour of FRP strengthened columns is evaluated covering all qualities of steel met in existing columns. Finally a strength model sensitive to bars' quality is proposed for the design of RC columns confined by FRP jackets, that requires no estimation of the effective failure strain of the FRP jacket, as it was found strongly related to the axial rigidity of the confining FRP device and the strength enhancement of the concrete core. The model is compared against an extensive database of experimental results. The proposed model provides remarkably accurate strength prediction results for the abovementioned strengthening applications.

**Keywords:** fiber reinforced polymers; strengthening; bars' buckling; finite element analysis; model.

## 1. Introduction

Structural interventions required in reinforced concrete columns of existing bridges, buildings etc., in order to upgrade their performance, may in some cases include the use of the fiber reinforced polymer (FRP) jackets as confining reinforcement instead of using conventional techniques. In such cases the design should take into account the confinement by the existing steel stirrups (see Mander et al 1988, Model Code 90 and Karabinis & Kiousis 1996 among others) as well as by the FRP jacket (see Wang & Restrepo 2001, Rousakis 2005 and Harajli 2006 among others). Steel stirrup confinement differs from the one by FRP sheet, as after steel yielding a more or less constant lateral pressure is exerted on the concrete core and the restriction of the lateral expansion weakens. Except for the evaluation of the behaviour of the confined concrete, also the variable behaviour of the compressed longitudinal bars should be considered, especially in cases of existence of inadequate stirrups' detailing (diameter or spacing, etc). In those cases, their effect on the strength and mainly on the axial strain at failure of the strengthened columns is expected to be significant. Preliminary analytical investigations of the contribution of the longitudinal bars, taking into account the parameters affecting the behaviour of the strengthened columns and of their interactions via modelling with finite elements (FE), can be found in the studies of Rousakis et al (2007) and Rousakis & Karabinis (2009). In the present study, a handy upgraded empirical model is proposed for the strength prediction of the RC columns strengthened by FRPs through external confinement.

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