ASSOCIAZIONE NAZIONALE MECCANICA TEORICA E APPLICATA

GIMC - GMA 2014

RACCOLTA DEI SOMMARI

XX Convegno Nazionale di Meccanica Computazionale
VII Riunione del Gruppo Materiali AIMETA

a cura di Elio Sacco - Sonia Marfia

UNIVERSITA' DEGLI STUDI DI CASSINO
E DEL LAZIO MERIDIONALE

DIPARTIMENTO DI INGEGNERIA
CIVILE E MECCANICA

Cassino 11 – 13 giugno 2014

www.gimc-gma2014.dicam.unibo.it

SOMMARI

GIMC

Gruppo Italiano di Meccanica Computazionale
AIMETA

Congresso GIMC-GMA-2014
11-13 giugno 2014

Limit analysis on FRP-strengthened RC members

Dario De Domenico[1, a *], Aurora A. Pisano[1,b] and Paolo Fuschi[1,c]
[1] University Mediterranea of Reggio Calabria, Dept. PAU
via Melissari, I-89124 Reggio Calabria, Italy
[a] dario.dedomenico@unirc.it, [b] aurora.pisano@unirc.it, [c] paolo.fuschi@unirc.it

Keywords: FE-based limit analysis, multicriteria approach, reinforced concrete elements, FRP-strengthening systems.

Many existing steel-reinforced concrete (RC) structures, including decks and beams in highway bridges as well as beams, slabs and columns in buildings, are being assessed as having insufficient load carrying capacity due to their deterioration, ageing, poor initial design and/or construction, lack of maintenance, corrosion of steel reinforcement or underestimated design loads. In other cases they no longer comply with the current standards and requirements because of changed load conditions or modification of structural system for some reason. It is both economically and environmentally preferable to upgrade these structures rather than replace/rebuild them, even more if rapid, simple and effective *strengthening* techniques are employed. In this context, flexural and/or shear repair and rehabilitation of RC structures with *externally bonded* fiber reinforced polymer (*FRP*) sheets, strips and fabrics is generally viewed as a valid and viable solution. Moreover, this technique can be carried out while the structure is still in use with relative ease of application and it can also be targeted at where the structural deficiency is more marked [1,2][1].

Experimental investigations confirm that a significant increase in flexural/shear capacity of the RC elements (up to about 125%) is achieved after the application of such FRP techniques [3]. Experiments also show the enhanced concrete confinement due to the FRP laminates, resulting in shifting the failure mode from brittle concrete crushing to more ductile steel yielding and/or FRP rupture [4]. In fact, the FRP strengthening system mitigates crack development and, as a result, increases ductility of the RC element as a whole.

On the other hand, to estimate the actual efficacy of the strengthening system, without performing expensive laboratory tests, as well as to design the proper repair interventions, to reach a given gain in load carrying capacity, analytical tools and predictive models are highly needed. In this contribution a numerical methodology, based on the theory of *limit analysis*, is adopted to predict the peak load of FRP-strengthened RC elements. The above considerations make indeed a limit analysis approach, as the one here proposed, both applicable and effective, especially when primary interest is in determining the limit (peak) load at collapse of the RC strengthened element.

The numerical methodology here followed, already used by the authors to predict the limit-state solution of RC elements (see e.g. [5]) and of pinned-joint orthotropic composite laminates (see e.g. [6]), is quite versatile and does not require any specialist program employing conventional finite element (FE) iterative analyses. A more general *multicriteria formulation* of the above-mentioned limit analysis methodology is here presented to appropriately describe the behaviour at collapse of structural elements of engineering interest strengthened by FRP techniques. Precisely, to simulate the constitutive behaviour of the three constituent materials, concrete is described by a Menetréy-Willam-type yield criterion endowed with cap in compression and formulated in terms of the Haigh–Westergaard coordinates; steel reinforcement bars (re-bars) are handled by a von Mises yield criterion; FRP strengthening laminates are governed by a Tsai–Wu-type criterion particularized in the case of an orthotropic lamina under plane stress conditions.

Operationally the iterative linear FE analyses are carried out on a structure with spatially varying moduli. The elastic parameters of the various FEs are iteratively adjusted in such a way as *to simulate*, with reference to the assumed yield criteria, a *collapse mechanism* and an *admissible stress field* for the given structure so as to apply the kinematic and the static approach of limit analysis, respectively.

On taking into account the nonstandard nature of the constitutive behaviour, the peak load value of the analyzed specimens is in facts numerically detected by an upper and a lower bound to it.

To demonstrate the actual capabilities of the proposed numerical procedure to deal with practical problems, large-scale prototypes of a few FRP-strengthened RC beams and slabs, experimentally tested up to collapse, are numerically investigated. The obtained results correlate quite well with the corresponding experimental findings taken from the relevant literature [4,7,8].

References

[1] FIB Bulletin 14. Externally bonded FRP reinforcement for RC structures, Task group 9.3, International Federation of Structural Concrete, (2001).

[2] American Concrete Institute ACI 440. Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures, ACI 440.2R-08 (2008).

[3] J. Dong, Q. Wang, Z. Guan, Structural behaviour of RC beams with external flexural and flexural–shear strengthening by FRP sheets, Composites: Part B 44 (2013) 604–612.

[4] M.A. Shahawy, M. Arockiasamy, T. Beitelmant, R. Sowrirajan, Reinforced concrete rectangular beams strengthened with CFRP laminates, Composites Part B 27B (1996) 225–233.

[5] A.A. Pisano, P. Fuschi, D. De Domenico, Peak loads and failure modes of steel-reinforced concrete beams: predictions by limit analysis, Engineering Structures 56 (2013) 477–488.

[6] A.A. Pisano, P. Fuschi, D. De Domenico, A layered limit analysis of pinned-joints composite laminates: Numerical versus experimental findings, Composites: Part B 43 (2012) 940–952.

[7] R. Al-Rousan, M. Issa, H. Shabila, Performance of reinforced concrete slabs strengthened with different types and configurations of CFRP, Composites: Part B 43 (2012) 510–521.

[8] D. Kachlakev, T. Miller, S. Yim, K. Chansawat, T. Potisuk, Finite Element Modeling of Reinforced Concrete Structures Strengthened with FRP Laminates, Final Report SPR 316 (2001), Oregon Department of Transportation Research Group, USA, May 2001.

Compendio dei Sommari del Convegno GIMC-GMA 2014:

- **XX Convegno Nazionale di Meccanica Computazionale**
- **VII Riunione del Gruppo Materiali AIMETA**

Cassino 11 – 13 giugno 2014

Università degli Studi di Cassino e del Lazio Meridionale
Dipartimento di Ingegneria Civile e Meccanica