Optimal design of the fiber-reinforcement to strengthen existing structures

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Abstract

The use of Fiber Reinforced Polymers (FRPs) for the strengthening of existing buildings has dramatically increased in the last decades. This technique has several advantages over standard retrofitting techniques such as flexibility, effectiveness and reversibility [1]. Applications are found indifferently on historical buildings made of brick masonry, or more recent constructions including concrete or reinforced concrete members. A suitable placement of unidirectional reinforcing strips provides structural elements with enhanced tensile strength, thus remarkably improving the load carrying capacity of the whole structure, see also [2].

This work investigates a topology optimization problem that simultaneously searches for the regions to be strengthened, along with the optimal local inclination of the reinforcement. To this purpose, the two-dimensional distribution of fiber-reinforcement is taken into account through the definition of an ad hoc orthotropic homogeneous medium, whose structural properties depend both on the density and the orientation of the fibers, see also [3,4]. A min-max problem is formulated on the local measure of the maximum equivalent stress in the underlying material, for a prescribed amount of fiber-reinforcement. Having the aim of providing a quite general procedure for isotropic concrete and orthotropic media (see e.g. brickwork or reinforced concrete), the Tsai-Wu failure criterion is implemented to define an equivalent stress that efficiently detects highly tensile-stressed regions throughout the existing structural component. Since the compressive strength of the fibers is not relied on in practical retrofitting applications, a suitable set of relaxed stress constraints is introduced in the formulation. The resulting multi-constrained min-max problem takes full advantage of the implementation of an ad hoc selection strategy that allows the number of local stress evaluations to be significantly reduced, following the approach presented in [5].

Numerical examples are presented to discuss the features of proposed procedure and the achieved optimal layouts, along with their possible application as preliminary design for structural retrofitting. Plane stress or plane strain problems are analyzed, assuming the in-plane stiffness to be given by the sum of that of the fixed underlying layer and that of the overlying fiber-reinforcement. The investigations refer to structural elements that can be modeled within the two-dimensional domain. Extension to three-dimensional problems, where a two-dimensional overlapping layer has to be designed, are also discussed and are currently under investigations.

Keywords: Topology optimization, Fiber-reinforcement, Orthotropic materials, Tsai–Wu failure criterion, Stress constraints, Min–max problems

References

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