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MODELING OF SMART CONCRETE BEAMS WITH SHAPE MEMORY ALLOY ACTUATORS

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In recent years smart material technology has become an area of increasing interest. Smart materials are multifunctional materials thought to execute other functions in addition to the structural one. Usually the main features required to smart materials are: sensing or self-sensing, actuating, self-healing. In Civil Engineering applications, a particular class of smart materials is the smart concrete, obtained adding special materials or devices to the traditional concrete (sensors and actuators). Among different types of smart concrete, a great attention is paid to the smart concrete obtained adding Shape Memory Alloys (SMA) actuators to the concrete. This kind of smart concrete can be used to control the mechanical features of prestressed structural elements, to obtain active confinement of columns, to control the dynamic features of a structure, to repair or to allow the self-repairing of concrete structural elements [1][2][3]. Topic of research interest is the last kind of application, as the improvement of the durability of structural elements is an important issue in civil engineering. Cracks are inevitable in concrete structural elements because of the low tensile strength of the material. Diffuse and deep cracks are very dangerous for the durability and mechanical resistance of the reinforced concrete members. In fact, because of the development of the cracks, the steel reinforcing bars are subjected to the oxidation processes which lead to reduce the steel resistance area.

Smart concrete obtained with SMA wires is used in order to reduce the width of cracks in the reinforced concrete elements by exploiting the two typical SMA behaviors: the pseudoelastic and shape memory effect. In this way the durability of concrete elements can be improved.

While a certain number of experimental investigations of concrete beams reinforced with SMA wires have been developed, a lack of studies concerning the numerical simulation of these kind of smart structures can be remarked. This can be due to the complexity of the numerical simulations of the response of concrete beams with SMA wires, because of the several nonlinearities governing the overall behavior of the structure. In fact, concrete is a cohesive material subjected to damage and fracture, SMA presents a very special nonlinear response. The few works available in literature concerning the modeling of SMA concrete elements, adopt simplified approaches both for reproducing the SMA and the concrete response. Different models have been proposed in literature over the years to simulate the response of concrete and SMA materials which can be used to reproduce the mechanical behavior of this special composite structural system.

In the present work, a computational strategy for the modeling of reinforced concrete beams with SMA actuators for cracks repair is developed. In particular, for the concrete, an original transition damage-fracture technique is proposed in order to simulate the microcrack arising, their coalescence and, finally, the macrocrack development. Microcracks are modeled adopting a nonlocal damage and plasticity approach, which is able to consider the tensile and compressive damaging, accumulation of irreversible strains and the unilateral phenomenon. Macrocracks are modeled using a cohesive zone interface which accounts for the mode I, mode II and mixed mode of damage, the unilateral contact and the friction effects. The interface models the transition from the continuum damage (simulating the presence of microcracks) to fracture [4][5]. A uniaxial SMA model able to reproduce both the pseudo-elastic behavior and the shape memory effect is adopted for the reinforcing SMA wires [6].
Finite element simulations are developed in order to reproduce the behavior of smart concrete beams subjected to three-point bending experimental tests available in literature. The construction phases of the beam are simulated and the loading history, consisting in three-point bending tests, are reproduced; in particular, the repairing phase due to pseudo-elastic behavior and shape memory effect is reproduced. Numerical results are compared with experimental data to validate the computational strategy.

REFERENCES

[1] Z. Deng, Q. Li and H. Sun, Behavior of concrete beam with embedded shape memory alloy wires, *Eng. Struct.*, Vol. **28**, n. 12, pp. 1691-1697, October 2006.

[2] Y. Kuang and J. Ou, Self-repairing performance of concrete beams strengthened using superelastic SMA wires in combination with adhesives released from hollow fibers, *Smart. Mater. Struct.*, no. 17, pp. 1-7, 2008.

[3] F. Daghia, A. Giammarruto and G. Pascale, Combined use of FBG sensor and SMA actuators for concrete beams repair, *Struct. Contr. Health Monit.*, no. 18, pp. 908-921, 2011.

[4] S. Marfia, E. Sacco and J. Toti, A coupled nonlocal interface damage model for FRP strengthening detachment, *Comput. Mech.*, Vol. **50**(3), pp. 335-351, 2012.

[5] Toti, S. Marfia and E. Sacco, Coupled body interface nonlocal damage model for FRP detachment, *Comput. Method. Appl. M.*, no. 260, pp. 1-23, 2013.

[6] S. Marfia, J. N. Reddy and E. Sacco, Superelastic and Shape Memory Effects in Laminated Shape-Memory-Alloy Beams, *AiAA J.*, Vol. **41**(1), pp. 100-109, 2003.