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A Finite Beam Element for Nonlinear Analysis of Concrete Structures Strengthened with FRP Laminates

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Abstract

This paper presents the formulation of a new reinforced concrete finite beam element for nonlinear analysis of concrete structures strengthened with FRP laminates. The formulation of the beam element accounts for the mechanical non-linearity associated with the nonlinear constitutive properties of the materials, the geometrical non-linearity due to the second order effects, and the bond slip between the beam and the laminate, that is included by assuming separate displacement fields in the beam and in the laminate. The proposed element is different from the so-called fiber elements, since the numerical integration is performed by higher order rules. Following the philosophy of the modern seismic codes, where the design requirements are specified in terms of acceptable levels of structural damage, a measure of the seismic performance based on suitable damage indices is proposed. In order to verify the capability of the finite element in reproducing the structural response of concrete structures strengthened with FRP laminates, particularly for the sudden drops of load capacity and brittle failure modes associated with laminate debonding, the results of a series of experimental static tests on reinforced concrete beams are considered. The direct comparison of numerical and experimental results proves the potentialities of the proposed formulation. A final application to the seismic analysis of a concrete bridge structure strengthened with FRP laminates highlights the effectiveness and applicability in engineering practice of the proposed approach, which allows an accurate evaluation and a comprehensive vision of the structural performance.