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A NONLINEAR MODEL FOR COMPOSITE BEAMS WITH LONGITUDINAL AND TRANSVERSE PARTIAL INTERACTION

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ABSTRACT

Composite beams are the most common form of composite structural element widely used in steel frame building construction and in bridge engineering for mid range steel bridges. Composite construction, which is now generally regarded as a structural type of its own, makes it possible to use with advantage the intrinsic mechanical properties of the constituent materials – steel in tension and concrete in compression, [5]. In fact, in such a structural system it is useful to distinguish three components: (1) steel girder (beam), (2) concrete plate, and (3) shear connectors. The role of shear connectors is critical. Composite beams vary in behaviour from the case wherein the connection between the steel beam and concrete plate exhibits very high stiffness and strength to the case where the bond between the two different components (materials) is non-existent. Usually, the connection is realized by means of discrete connectors in the form of headed shear studs welded to the top flange of the steel beam, resulting in partial connection. The shear stud connectors are not only an easy and economic solution but they provide some measure of ductility as well, what may be advantageous in the structural systems located in earthquake-prone zones.

In this contribution we consider the quasi-static bending problem of steel-concrete composite beams, accounting for partial interaction both in longitudinal and transverse directions. The longitudinal partial interaction leads to mutual slip of the constituents while the transverse one may result in separation of the plate from the top beam flange. Different aspects of the nonlinear problem for composite beams have been studied in many works, for example see [1, 3, 6, 7] where further references are included. For the kinematical description of the composite beam of length L we use four displacement fields of the transverse (vertical) $w_1=w_1(x)$, $w_2=w_2(x)$ and longitudinal (horizontal) $u_1=u_1(x)$, $u_2=u_2(x)$ displacements of the centroids of part 1 (steel girder) and part 2 (reinforced concrete plate). For component materials, both structural and reinforcement steels and concrete, piecewise linear elastic-plastic constitutive laws are adopted [4]. On the steel-concrete interface a piecewise linear elastic-plastic law is assumed, allowing

for permanent longitudinal slip and debonding of the beam and plate. After separation the unilateral contact conditions with friction are supposed. This constitutes a difficult problem due to the fact that the occurrence of evolving plastic range along and through-the-thickness of the composite beam, as well of unilateral contact on the interface are not known in advance (free-boundary value problem).

In the linear elastic case we have obtained analytical results which show characteristic features of the composite beam response, in particular the impact of partial interaction. For the nonlinear case we have to resort to numerical techniques. We have used the finite element method with a proper selection of basis (shape) functions in order to avoid slip locking (longitudinal displacements approximated by second-order polynomials, and vertical displacements – third-order polynomials). In a general case, the deformation process of the composite beam is solved incrementally as a series of linear complementarity problems (KKT conditions). The complementarity approach provides a unified formulation for plasticity and unilateral contact conditions [4, 2]. Some of our computer programs are still under further development. Our aim is to apply and test both classical (direct) and iterative methods for the complementarity problem under consideration. The numerical results we have obtained are interesting and indicate how complex the response of such a simple heterogeneous engineering structure can be.

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