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Dimensionless formulation and comparative study of analytical models for composite beams in partial interaction

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ABSTRACT

Steel–concrete composite beams are widely utilized as cost-effective structural solution in both buildings and bridges. Partial interaction through the possible occurrence of slips at the interface between the two connected members, strongly affects the behaviour of composite members and, therefore must be incorporated in theoretical models dealing with composite members. In addition, shear deformability of the two connected layers cannot be ignored in stocky members. Several computational models simulating the behaviour of composite beams including partial interaction and shear deformability with various degree of sophistication are currently available in the scientific literature. The present paper focuses on the background and the mechanical assumptions adopted in these models as well as structural characteristics which actually govern their predictions. Based on the kinematic assumptions involved, a threefold classification is proposed. The paper further clarifies the hierarchy between the three groups of models. To do so, the governing equations for each group of models are transformed into a proper dimensionless form by using mechanically sound dimensionless expressions of all functions of interest involved in the description of the mechanical response of the composite beam. A thorough parametrical study is presented which quantifies the influence of the identified dimensionless parameters. Furthermore, the study clearly indicates possible threshold values beyond which certain effects become negligible.

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1. Introduction

Steel–concrete composite beams are widely used in both buildings and bridges as a structurally-efficient and cost-effective solution [1]. However, the analysis of steel–concrete composite beams is rather challenging from a computational point of view since the mechanical behaviour of the coupled system is complex and characterized by the occurrence of slips at the interface. Such slip results in partial interaction even in cases of full shear connection, as defined by Eurocode 4 [2] for design purposes at the Ultimate Limit States. Several theoretical models, characterized by different levels of approximation, have been proposed to simulate the structural response of elastic composite structures in partial interaction [3,4]. Such models have been also the basis for approximate solutions derived using either the finite difference method [5,6] or the finite element method, the latter being the driving force behind various advanced formulations such as the direct stiffness/flexibility method [7], force-based FE models [8]and mixed formulations [9,10,23]. These formulations have been used to investigate the time response as well as the inelastic response of composite beams with interlayer slips.

Albeit the specific objectives of the various contributions (i.e., the long-term behaviour of composite steel–concrete beams [11,12,22], the response under fire conditions [13], geometrically nonlinear analysis [24], analysis of frames [25] etc…) as well as the particular solution methods implemented therefore, common assumptions of the above formulations can be easily recognized. Indeed, the transverse displacement of both members are generally considered equal (no uplift) all along the beam. In fact, several studies have demonstrated that the overall structural response is weakly influenced by considering possible relative displacements between the concrete slab and the steel beam [14]. Therefore considering independent deflection for each layer unnecessarily complicates the model equations as we are dealing with highly nonlinear relations which govern unilateral contact conditions with or without friction. Consequently, a unique function describing the transverse displacement of both components is generally assumed for the sake of simplicity and without significant loss of accuracy [15,16,17]. Based on the kinematical assumptions underlying the different theoretical models, the formulations that have been proposed for planar steel–concrete composite beams in partial interaction can be basically classified in the following three groups:

1. *Shear-rigid composite beam models* (Group 1): these are models where shear deformability is neglected for both connected layers each of which is modeled according to the well-known Bernoulli Beam Theory [3];

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