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Evaluation of the deflection of steel-concrete composite beams at serviceability limit state

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ABSTRACT

The paper investigates the response of steel–concrete composite beams at serviceability limit state. Both cases of propped and unpropped steel beam during the pouring of the concrete slab were considered. The maximum vertical displacements in the short- and long-term were evaluated for simply supported and continuous composite beams using accurate finite element models. The numerical results were compared with the maximum displacements obtained using the simplified approach suggested by the Eurocode 4. This formulation which, in the case of continuous beams, accounts for the nonlinear behavior of the component materials, was found to be often non-conservative. On the basis of the outcomes of an extensive parametric analysis, a simple design criterion was proposed. This method is based on the limitation of stresses in the steel profile below the yield limit, and on the use of a simple relationship to account for the connection flexibility. The proposed procedure to calculate maximum displacements of composite beams provides conservative results, with a level of accuracy suitable for practical design.

1. Introduction

Modern codes of practice such as the Eurocode 4 [1], CNR 10016 [2] and LFRD Specification [3] recommend checking serviceability limit state of steel–concrete composite beams to ensure that functionality and durability will not be compromised during the service life. The main quantity to consider in the design for serviceability limit state is the maximum deflection. Such a quantity is influenced by several phenomena such as concrete cracking in tension zones, time-dependent behavior of concrete (creep and shrinkage), and yielding of reinforcing and construction steel. It should be noted that the Eurocode 4 [1] does not prescribe any stress control of the steel profile and, therefore, implicitly allows plasticization even under the service load. Steel yielding, hence, may significantly affect the beam behavior, particularly for steel beams which are left unpropped during the concrete placement [4,5]. Another important parameter to consider is the interlayer slip at the interface between the concrete slab and the steel profile. Such a parameter is particularly important when the shear connection is partial, i.e. when the number of connectors is less than the minimum number required for a full strength shear connection. This case is fairly common for unpropped beams as in many cases the design of the steel profile is governed by the ultimate limit state of flexural strength before the steel beam is connected to the concrete slab. Adopting a reduced number of connectors allows some cost saving but, at the same time, leads to reduction in stiffness and strength of the composite beam that should be considered in design.

Due to the complexity of the problem, an accurate investigation of the behavior of steel-concrete composite beams at serviceability limit state can be carried out only using accurate numerical models [6–11]. The analysis is particularly demanding in the long-term, where creep and shrinkage of concrete increases the deflection and, for continuous beams, causes concrete cracking and moment redistribution from the interior supports to mid-spans. Nonlinear analysis is usually carried out only for design of very demanding structures such as bridge girders. Conversely, approximate methods can be used for beams which are part of composite frames in residential and office buildings. In this respect, current codes [1–3] suggest simplified procedures which accounts for material nonlinearity and shear connection deformability. However the latter contribution is usually considered only in the case of partial shear connection, thus often leading to non-conservative results for beams designed with full strength shear connection [6,12,13]. Creep and shrinkage of concrete were found to markedly increase the deflection of composite beams in the long-term [14]. Simplified methods such as the 'effective modulus method', the 'mean stress method', and the 'age-adjusted effective modulus method' were recommended, respectively, in [1,15], and [12] in order to account for those time-dependent phenomena.

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