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Creep and Shear-Lag Effects in Composite Beams with Flexible Connection

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1. Problem statement

In modeling steel-concrete composite beams, two kinematical aspects should be considered: the deformability of the shear connection and the non-uniform distribution of the longitudinal displacements in the slab (shear-lag). The deformability of the shear connection allows a slip at the beam-slab interface, increasing the global flexibility of the structure, while the shear-lag effect implies a non-uniform distribution of stresses in the slab. Furthermore, the behaviour of the composite beam is strongly influenced by the concrete time-dependent effects [1]. Although the effects of creep, connection deformability and shear-lag have been extensively examined in literature, their interaction is not completely known.
For this purpose, a general analysis for composite beams has been developed to encompass shear-lag effect, flexible shear connection, creep and shrinkage of the concrete [2]. Starting from the definition of a suitable displacement field which takes into account slipping at beam-slab interface and slab shear deformation, a global balance condition is obtained by means of the virtual work principle. By assuming a linear elastic behaviour for steel beam and shear connection, and a linear viscoelastic behaviour for the concrete slab, the problem is governed by a coupled system of four integral-differential equations. The unknowns of the problem are the functions describing beam deflection, axial displacements of the steel beam and the concrete slab, and intensity (along the beam axis) of the shear-lag effect introduced by means of a suitable shape function for the shear warping of the slab cross section (depending on the point of the cross section only). In particular, the shape function is a quadratic function constant on the slab depth, null at the beam-slab interface and satisfying conditions ensuring local equilibrium at the slab free edges.
Given the generality of the creep function adopted, a closed form solution cannot be achieved for the system. In order to obtain an accurate numerical solution, the system is solved by introducing two discretizations: one for the time interval, which permits solving the integral-differential problem by a step-by-step procedure considering a set of simpler differential problems, and the other for the beam axis in order to apply the finite differences method.

2. Principal results

An extensive numerical parametric analysis, carried out for beams with different geometry and subjected to different restraints and load conditions, has made it possible to obtain some information on the complex time dependent behaviour of composite structures. In particular, the time evolution of the shear-lag and the mutual influence between shear-lag and connection deformability have been studied in detail. For the sake of brevity, only results related to an isolated case (but which can be qualitatively extended to a wide class of composite structure) are reported here.
Fig.1 shows the numerical results obtained for a two-span continuous beam. The creep analysis was performed with the CEB creep function [3] by considering the following values for concrete strength and relative humidity: f_{ck}=30MPa and RH=50%. The solution at loading time t_0=28 days (elastic solution) is compared with the viscoelastic solution (t_∞=25550 days). Furthermore, results obtained taking into account the shear-lag effect (curves denoted by SL) are compared with those obtained under the classical hypothesis adopted for composite beams with flexible shear connection, namely preservation of plane cross section for the steel beam and the concrete slab considered separately (curves denoted by P). The most important results are summarised in the sequel.

1. The beam axis deflections notably increase as a consequence of the time-dependent behaviour of the concrete, while they are less sensitive to the shear-lag effect (Fig. 1a).

2. The shear-lag effect, as is well known, strongly modifies the stress distribution in the slab only in the neighbourhood of the intermediate support, by significantly increasing the value which would be obtained by assuming the plane cross section hypothesis for concrete slab and steel beam (Fig. 1b).

3. Influence of the shear connection stiffness (ρ) on shear-lag is shown in Fig. 1c, where the elastic values of the stresses σ_{SL} and σ_P at the intermediate support cross section are compared. Increasing ρ, shear-lag stress σ_{SL} increases more than σ_P as shown by the dashed curve related to the ratio σ_{SL}/σ_P. The coupling between the shear-lag effect and the shear connection stiffness is thus evident.

4. Fig. 1d shows the influence of creep on the shear-lag effect. The time evolution of the ratio between $\Delta\sigma$ and σ_{SL} (see Fig. 1b) is reported for three different values of the shear connection stiffness. Such a ratio permits defining the slab effective width b_{eff} (adopted by the principal technical codes, e.g. ENV 1994-2) as

$$b_{eff} = \frac{1}{\sigma_{SL}} \int_{-b/2}^{b/2} \sigma_c dx = b - \frac{\Delta\sigma}{\sigma_{SL}} \int_{-b/2}^{b/2} f(x) dx$$

where b is the real value of the slab width and $f(x)$ is a function depending on the cross section only. It is evident that such a ratio, even if it depends on the ρ value, remains almost constant in time showing a substantial uncoupling between creep and shear-lag effect.

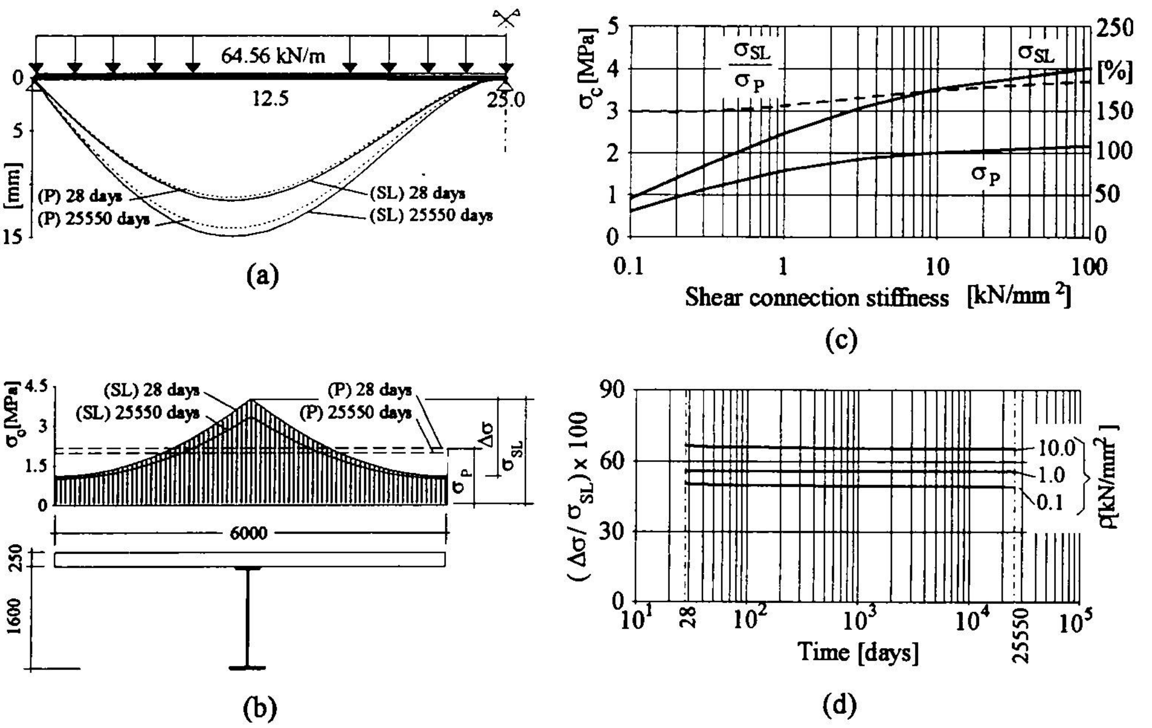

Fig. 1. (a) Influence of shear-lag and concrete creep on the beam deflections. (b) Concrete creep effect on the slab stress distribution. (c) Influence of the shear connection stiffness on the shear-lag effect. (d) Influence of the concrete creep on the shear-lag effect.

3. References

1 Dezi, L., and Tarantino, A.M. (1993), "Creep in composite continuous beams. I: Theoretical treatment." *J. Struct. Engrg. ASCE,* 119(7), 2095-2111.

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3 "CEB FIP model code 1990." (1988). *C.E.B. Bullettin d'information n.190,* C.E.B. F.I.P. Comité Euro-International du Beton, Paris, France.