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Estimation of the bending stiffness of rectangular reinforced concrete beams made of steel fibre reinforced concrete

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A method of calculating the location of the neutral axis of a rectangular steel fibre reinforced concrete cross section before and after cracking, and its moments of inertia relative to this axis is proposed. Moreover, the method of calculating the cross section's geometrical characteristics for both the cracked stage and the uncracked stage is based on a model of fibres distribution along the length of the beam. Consequently, two algorithms for estimating the immediate and long-term deflections of steel fibre reinforced concrete beams are proposed. One of the algorithms is for uncracked beams and the other for cracked beams. The algorithms have been positively experimentally verified.

Keywords: *steel fibre reinforced concrete, steel fibres, stiffness, moment of inertia, deflections of beams*

1. Introduction

Already the first attempts at designing, making and using reinforced concrete elements showed that a major factor which determines their practical usefulness is their deformation capacity. In the case of beams, it means the capacity to undergo immediate and long-term deflection. An immediate deflection arises immediately after the element is loaded while a long-term deflection occurs after some time. Respectively immediate stiffness and long-term stiffness correspond to the above types of deflection. The increase in the deflection of reinforced concrete beams and steel fibre reinforced concrete beams over time is due to the fact that concrete is a rheological material, mainly because of its creep (i.e. an increase in strain over time under a constant load). However, the problem of the deflection of reinforced concrete beams or fibre reinforced concrete beams is much more complex and the size of the immediate and long-term deflections depends not only on the creep strain, but on many other factors as well.

The problem of immediate and long-term deflections has been solved for reinforced concrete elements, although research aimed at improving the existing theories, based on different models (taking cracking into account) of stiffness distribution along the length of the element, is still continued [1–2]. According to one of the most popular concepts, stiffness is constant along the element's length [3–5].

In the case of steel fibre reinforced concrete beams Ezeldin and Shiah [6] proposed to estimate immediate and long-term deflections by means of an algorithm based on the moment-curvature relation or the load-displacement relation. The algorithm requires that the characteristics of the fibre reinforced concrete be known. Idealized (e.g. stress-strain) relations for fibre reinforced concrete under compression can be assumed on the basis of [7].

The calculation of long-term deflections of reinforced concrete beams and fibre reinforced concrete beams becomes even more complicated since concrete creep and shrinkage need to be considered. The amount of experimental data on creep for fibre reinforced concretes is rather small [6]. When developing their algorithm Ezeldin and Shiah took into account the experimental results concerning the shrinkage and creep of concrete, presented in respectively [8–9] and [8]. Consequently, it was proposed to calculate shrinkage strain and creep strain according to the guidelines of [10].

Cross sectional moment of inertia J should be calculated in accordance with the theory of reduced cross section, taking into account the area of the compressed fibre reinforced concrete and substituting this area for the area of the steel. Unfortunately, this way of calculating the stiffness (and particularly the moment of inertia) of the cross section does not take into account the distribution of fibres in the cross section or along the length of the beam. The problem of describing the distribution steel fibres in the cross section and along the length of the beam was analyzed by Kamiński and Bywalski [11] who built a simulation model of fibres distribution [12]. The model can be used to estimate the moment of inertia of the beam cross section.

2. Proposed modification of EC2 method

2.1. Assumptions

On the basis of their own experimental results the authors have modified the Eurocode 2 [13] method of estimating deflections, by taking into account the contribution of the fibres to the increase in the moment of inertia of any cross section. For this purpose the above mentioned model of fibres distribution in the cross section and along the length of the element was used. The proposed approach distinguishes between uncracked and cracked beams. In the latter case, the authors propose to neglect the fibres located in the zone of tensile strains greater than 2.5‰. The proposed modifications are described in detail later in this paper.

The authors have also proved that the influence of steel fibres on creep strains is negligibly small [14], which means that the magnitude of creep strains is determined by the concrete matrix. Consequently, the existing methods of calculating creep strains for concretes without fibres can be employed. The authors propose to use the method based on the MC 90 model (Model Code 1990) to calculate the creep coefficient (also for steel fibre reinforced concretes). Model Code 1990 was described in detail in the CEB Bulletin [15].