Engineering Structures 33 (2011) 2772–2780

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Assessment of the flexural capacity of RC beam/column elements allowing for 3d effects

Gerasimos M. Kotsovos

Laboratory of Concrete Structures, National Technical University of Athens, 10433 Athens, Greece

ARTICLE INFO

Article history:
Received 24 January 2011
Received in revised form
1 April 2011
Accepted 1 June 2011
Available online 1 July 2011

Keywords:
Beams
Flexural capacity
Reinforced concrete
Strain
Stress
Tests
Triaxial stress conditions

ABSTRACT

The paper describes an experimental investigation of the deformational response and the stress conditions developing in the compressive zone of reinforced concrete beam-like structural elements in bending and bending combined with axial force. The results obtained confirm the findings of earlier work and demonstrate that the compressive zone at its ultimate-limit state is characterised by the development of triaxial rather than uniaxial – as widely considered – stress conditions. These findings form the basis for introducing a simple modification in the method currently used for calculating flexural capacity and it is shown that, by complementing the proposed method with an approach that takes into account the effect of yielding of the compression reinforcement on structural behaviour, it is possible to achieve predictions of flexural capacity which are considerably closer to experimentally established values than the values obtained through the use of currently adopted methods.

1. Introduction

In order to safeguard against shear types of failure, reinforced concrete (RC) structures are designed such that their load-carrying capacity corresponding to flexural capacity is smaller than the value corresponding to shear capacity by an adequate margin of safety. This objective is considered possible to achieve by basing shear design on the use of the shear force diagram corresponding to flexural capacity rather than to the design load. In this approach, implicit is the assumption that the calculated value of flexural capacity is at least equal to its "true" value, since the use of a smaller value in shear design may not prevent a shear type of failure occurring before a structural element's flexural capacity is exhausted.

However, it is easily established by experiment that the current methods of calculation invariably underestimate (often by a significant margin) the flexural capacity of linear reinforced concrete (RC) elements, such as beams and columns [1]. This problem is widely recognised in RC capacity design and current code provisions aiming to safeguard against shear types of failure recommend the use of an "over-strength" factor which leads to an increase in flexural capacity up to 40% in certain cases [2]. The causes of the underestimate are commonly attributed to discrepancies between the true and assumed material properties, and, in particular, to the strain hardening of the steel reinforcement, which is not usually allowed for in the calculation [2].

Allowing for strain hardening results in an increase of the tensile force sustained by the flexural reinforcement, which, for purposes of internal force equilibrium, must be balanced by an increase of the force sustained by concrete in the compressive zone. Since the calculation of flexural capacity is based on the assumption of a uniaxial stress field in the compressive zone, the increase of the force sustained by concrete can only occur through an increase of the depth of the compressive zone. The latter increase inevitably leads to a reduction of the internal force lever arm and this sets an upper limit to the resulting increase in flexural capacity. As a result, even when allowing for strain hardening, current methods of calculation may still underestimate flexural capacity.

However, there is published experimental evidence which shows not only that adopting uniaxial stress-stain characteristics is incompatible with the measured deformational response of concrete in the compressive zone of an RC beam (without compression reinforcement and stirrups) at its ultimate-limit state in flexure, but, also, that the stress conditions within this zone are triaxial rather than uniaxial [3]. In fact, these stress conditions have been found to develop due to transverse deformation compatibility purposes which are totally ignored by current methods of calculation [3].

The present work uses the above findings as the basis for introducing a simple modification in the method of calculation of flexural capacity which is shown to virtually eliminate the

E-mail address: gkotsov@gmail.com.

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.06.002