Engineering Structures 124 (2016) 418–428

Contents lists available at ScienceDirect

Engineering Structures

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

Effect of arrangement of tensile reinforcement on flexural stiffness and cracking

Viktor Gribniak [a,b,*], Alejandro Pérez Caldentey [c,d], Gintaris Kaklauskas [a,b], Arvydas Rimkus [a,b], Aleksandr Sokolov [a,b]

[a] Research Laboratory of Innovative Building Structures, Vilnius Gediminas Technical University, Vilnius, Lithuania
[b] Department of Bridges and Special Structures, Vilnius Gediminas Technical University, Vilnius, Lithuania
[c] Polytechnic University of Madrid, Madrid, Spain
[d] FHECOR Consulting Engineers, Madrid, Spain

ARTICLE INFO

Article history:
Received 16 April 2015
Revised 19 April 2016
Accepted 20 June 2016

Keywords:
Reinforced concrete
Experiments
Deformations
Tension stiffening
Cracking

ABSTRACT

Due to the highly complex cracking behaviour of reinforced concrete structures, their design for serviceability is one of the most challenging tasks of engineering practice. Existing test data support a general inference that the deformation behaviour of concrete elements is affected by the arrangement of reinforcement in the tensile zone. Most of the current design approaches are based on the experimental data of laboratory specimens with simplified arrangement of the reinforcement. Consequently, the corresponding models are often inadequate to predict deformations and cracking of elements with non-conventional distribution of the bars. In the current study, the number of the reinforcement layers is found to correlate with the flexural stiffness. The paper also compares the crack width and crack spacing experimentally determined in the beams with different numbers of reinforcement layers. The results to some extent seem to be in conflict with the generally accepted concept relating crack widths to the cracking distances. Although the observed crack distances of the beams with three layers of bars were larger, their maximum crack openings were smaller than in the conventionally reinforced specimens with the same reinforcement ratio.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

One of the causes of deterioration of reinforced concrete structures is excessive cracking resulting from either restrained deformation or external loads. Reinforcing layout is designed for resisting tensile stresses in particular regions of concrete structures. A proper arrangement of reinforcement offers an alternative to increase the flexural stiffness and alleviate the cracking problems [1]. Following current design regulations of spacing and dimensioning of bars, it is common to distribute tensile reinforcement in several layers [2]. The consequent increase of number of reinforcement layers may improve deformation properties and cracking resistance of concrete members [3,4]. In order to optimize reinforcement schemes and to design cost effective structures, the effect of the arrangement of reinforcement bars in the tension zone on serviceability properties (deformations and cracking) requires an assessment and consideration for design.

Most of the current design approaches are based on experimental data of laboratory specimens with simplified arrangement of reinforcement and conventional width of the concrete cover [5,6]. Consequently, the corresponding predictions are in good agreement with the experimental results of conventionally reinforced elements [7,8], but these models are often inadequate to predict the cracking behaviour of elements with non-conventional arrangement of the bars [9–11].

Existing test data support a general inference that the flexural behaviour of concrete beams is affected by the arrangement of reinforcement bars in the tensile zone [9,12]. In cracking problems, this effect is often related to the effective area issue [6,13,14]. In deformation analysis, the increase in flexural stiffness can be accounted for by modification of the effective depth [15,16]. In the present study, the latter possibility is illustrated by fitting predictions by Model Code 2010 [17] to achieve best agreement between the theoretical and the experimental moment-curvature relationships. The paper also deals with the effect of distribution of the tensile reinforcement on the flexural cracking. It compares the crack width and crack spacing experimentally determined in the beams with different numbers of reinforcement layers. To

* Corresponding author at: Department of Bridges and Special Structures, Vilnius Gediminas Technical University, Sauletiekio av. 11, Vilnius LT-10223, Lithuania.
E-mail address: Viktor.Gribniak@vgtu.lt (V. Gribniak).

http://dx.doi.org/10.1016/j.engstruct.2016.06.026
0141-0296/© 2016 Elsevier Ltd. All rights reserved.

assess the crack distance, the authors propose a numerical procedure for analysis of digital images.

2. Experimental investigation on deformations and cracking of RC beams

Test specimens with different arrangements of reinforcement in the tension zone are considered. The experimental program includes bending tests of nine beams reinforced with glass fibre reinforced polymer (GFRP) or steel bars. Surface shapes of the reinforcement bars are presented in Fig. 1. For the purpose of comparative analysis, all the test specimens had identical concrete cross-sections with a similar concrete strength f_{cm} and two different reinforcement ratios p (0.6 and 1.0%).

2.1. Description of test specimens

The main parameters of the beams are listed in Table 1 with sectional notations evident from Fig. 2. Other parameters presented in the table are the concrete ∅150 × 300 mm cylinder compressive strength ($f_{cm,28}$) and (f_{cm}) at 28 day and at age of testing (t); the elastic modulus of steel (E_s) and GFRP (E_f); the ultimate GFRP strength (f_u) and steel yielding strength (f_y) of the reinforcement bars. Tensile strength and elasticity modulus of concrete (required for theoretical assessment of the serviceability parameters by the Model Code 2010 [17]) were calculated using the material properties from Table 1.

The presented data is part of large experimental program [18]. The beams were made using the same concrete grade (C 37) from different local producers. This investigation considers two concrete mixes given in Table 2 and denoted as *Mix A* and *Mix B*. As a part of the test program supported by the *Research Council of Lithuania*, this study employs original notations of the specimens. Letter "*S*" refers to the type of elements (in Lithuanian "Sija" = "Beam"); the first number corresponds to the level of reinforcement ratio p ("*2*" refers to $p \approx 0.6\%$ and "1" to $p \approx 1.0\%$); "*nm*" refers to non-metallic (GFRP) reinforcement. The experimental beams were cast using steel formworks. The beams were unmolded in 2–3 days after casting. The specimens were cured at an average relative humidity (*RH*) of 73% and a temperature of 20 °C.

2.2. Testing procedure

The experimental beams with a nominal length of 3280 mm were tested under a four-point bending scheme with 1000 mm shear spans as shown in Fig. 3 that also gives the strain gauge position. The specimens were loaded with a 1000 kN hydraulic jack in a stiff testing frame. The test was performed with small increments (2 kN) and paused for short periods (about 2 min) to take readings of the gauges and to measure crack development. On average, it took 50–80 load increments with a total test duration of 3 h. The testing equipment acting on the beam weighed 2.3 kN. The latter summed up with the beam's own weight induced a 3.5 kN m bending moment at mid-span.

Moment-curvature diagrams were obtained in two ways: from deflections and from concrete surface strains, both recorded in the pure bending zone. Concrete surface strains were measured throughout the length of the pure bending zone, using mechanical 200 mm gauges. As shown in Fig. 3 (view 'A'), four continuous gauge lines (with five gauges in each line) were located at different heights. The two extreme gauge lines were placed along the top and the bottom reinforcement whereas two other lines were located 60 mm off these lines. To measure deflections, linear variable differential transducers (L_1–L_8, see Fig. 3) were placed beneath the soffit of each of the beams. Previous studies [19–22] revealed good agreement between the moment-curvature diagrams obtained from the deflection of the pure bending zone and strain measurements. In the present study, the moment-curvature response of the beams was assessed using the strains averaged along each of the gauge lines shown in Fig. 3. Following the methodology detailed in Refs. [19,20], the curvature averaged through the pure bending zone is calculated as:

$$\kappa = \frac{1}{6}\sum_{l=2}^{4}\sum_{k=1}^{l-1}\frac{D_k - D_l}{h_{kl}}. \tag{1}$$

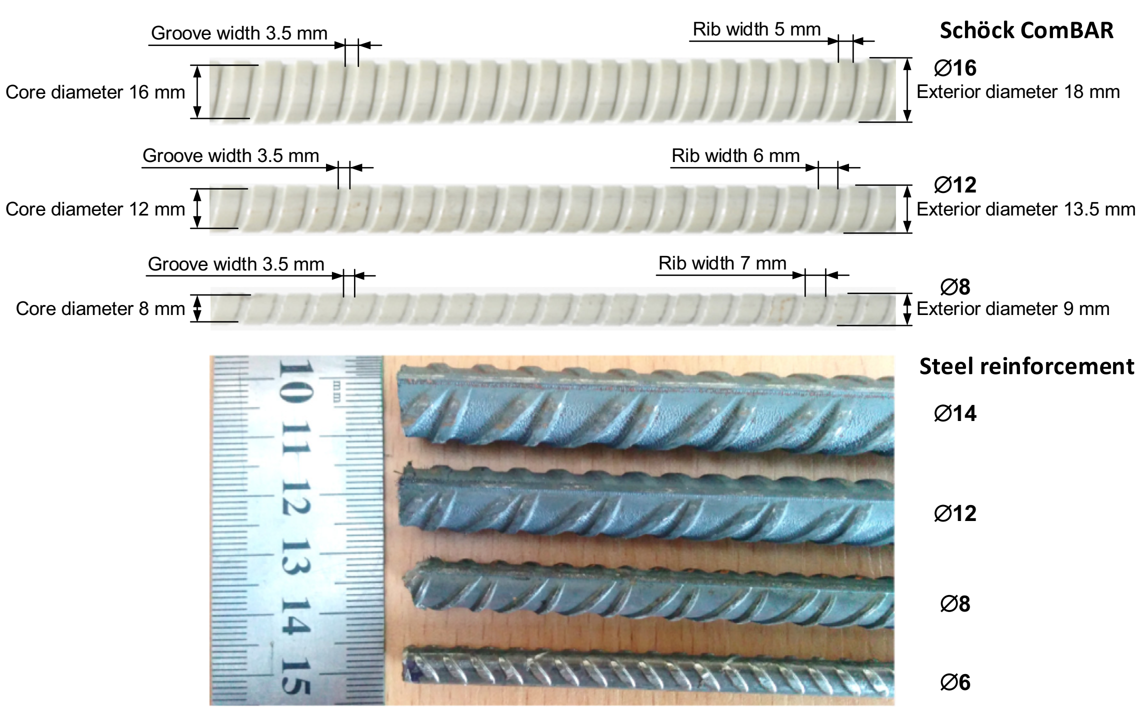

Fig. 1. Reinforcement bars.

Download English Version:

https://daneshyari.com/en/article/265637

Download Persian Version:

https://daneshyari.com/article/265637

Daneshyari.com