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Research Paper

The Affection of “k_b” Coefficient in the Calculation of the Crack Width

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Abstract: The calculation of the maximal crack width, include the effect of adhesion between FRP bars and the concrete around them. The value of “k_b” coefficient is given by recommendations, but is still unclear his true value. The adhesion between concrete and the bars depends in concrete compressive strength, bar diameters and the type of bar surface. In absence of sufficient experimental data, the codes and the recommendations give to us “k_b” values that are part of analytical calculations for crack width value. In this article, in base of experimental testing, are given values of “k_b” coefficient for the beams reinforced with GFRP and CFRP bars. The beams are tested under flexure. The effect of FRP reinforcement used will be evaluated. The test result, show that the coefficient “k_b” for the beams reinforced with CFRP are lower than the same coefficient for the beams reinforced with GFRP.

Keywords: crack width, GFRP bars, CFRP bars, concrete beam, serviceability state design

Introduction

Because of the low stiffness the concrete beams reinforced with FRP bars, shows more deflections and bigger crack width than concrete beams reinforced with steel bars. The control of crack width is a very important criterion in design of concrete elements reinforced with FRP bars. Concrete cracks are affected by his limits to be deformed and usually are expected to happen in the serviceability limit state. The design of concrete structures reinforced with FRP bars is limited by the crack width, when according to CSA is recommended for exterior structures crack width limit is 0.5 mm and for interior elements 0.7 mm. Usually, depending on experimental testing codes, beam structures and plate structures are loaded in one or two points. Many scientists have admitted that 30% of bending moment capacity (0.3 M_u) of beams is the rational value for the phase of serviceability limit state design loading of elements reinforced with FRP rods. Beams reinforced with sand coated GFRP bars, produce greater number of cracks with lower widths than the beams reinforced with helically-grooved bars. This confirms better bond adherence between sand coated bars and concrete. Bar diameters also affect in the crack width value. The values of “k_b” coefficient expressed in literature are different, so they show us different values of crack width. The development technology of producing FRP bars, have given to us different mechanical properties. In many countries are not applied codes for calculating crack width in concrete structures reinforced with FRP bars. The comparison of crack width values from different codes and experimental testing has showed that some codes gives approximate values and some other codes gives greater values than experimental values. Experimental testing has showed that increasing protective layer from 38 mm to 50 mm cause a decrease in 36 % of the value of “k_b” coefficient for the sand coated GFRP bars. Sand- covered fibers bars show better bond resistance than helically grooved surface. (Hota *et al*.2006)

The evaluation of k_b coefficient is first expressed by ACI and then was modified by Gergly-Lutz for concrete structures reinforced with FRP bars instead of conventional steel. Frosch has concluded that “k_b” value is 19% greater than Gergely-Lutz value. Frosch proposes “k_b” value from 0.6-1.72 in average 1.1±0.31. (Frosch *et al.,* 1999) It must be noted that the k_b value given in codes and manuals should be used when there are no experimental data and it takes in consideration only the type of bar surface. CSA and ACI gives this formula for calculation of maximal crack width (Gergely-Lutz *et al.,* 1968; CSA, 2012, 2014; ACI Committee 440, 2003, 2006).

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$$w = 2\frac{f_f}{E_f}\beta k_b \sqrt[3]{d_c^2 + \left(\frac{s}{2}\right)^2} \quad (1)$$

Except equation 1, equation 2 given from ACI 440 is used also to calculate “k_b” value

$$w = \frac{2.20}{E_{frp}} \cdot \beta \cdot k_b \; f_f \sqrt[3]{d_c \cdot A} \quad (2)$$

From experimental data is said that should be valued the case when FRP bars are in two rows. In this case, the appropriate value for “k_b” is 1.4.

Material and Methods

For experimental testing are used 3 series of beams reinforced with GFRP and two series with CFRP for evaluation of “k_b” coefficient. The cross section of beam is 13 cm width and 22 cm of high. Length of the beam is 220 cm. Beams are reinforced with GFRP and CFRP bars in tensile zone with diameters 6, 8, 10 mm. Mechanical properties of the bars are given in Table 1. (Naser *et al.*2019)

Table1. **Mechanical properties of GFRP and CFRP bars**

	GFRP			CFRP	
d (mm)	Ø6	8Ø	10Ø	8Ø	10Ø
Strain ε_{frp}	0.0204	0.0234	0.0256	0.0095	0.015
Tensile strength [MPa]	1022.10	1108.2	1194.3	1265.4	2000
Elasticity modulus [GPa]	55			155	

The beams are loaded in four points bending like showed in Figure 1 (Tighiouart *et al.*1999), under the MCC8 Controls equipment

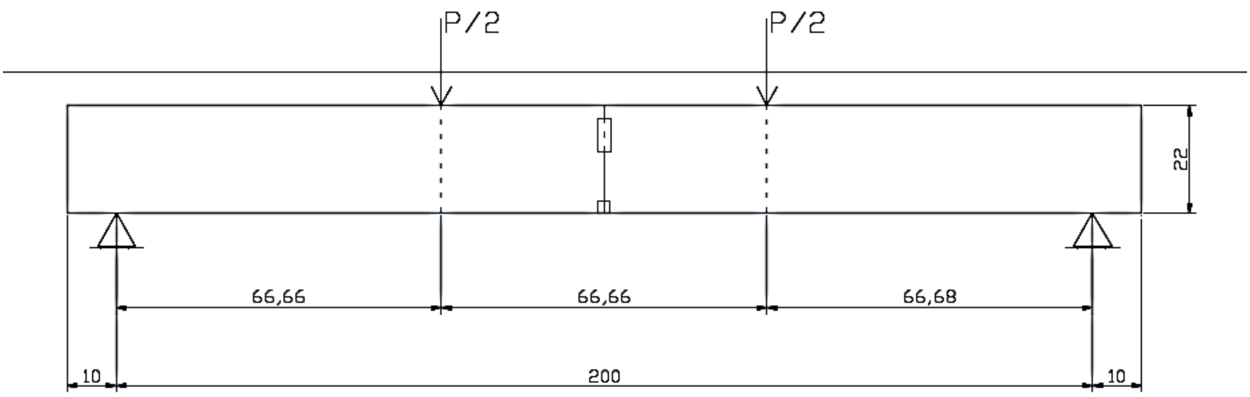

Figure 1. Loading scheme of the beams

In Figure 2 is showed the type of reinforcement used in beams, the down layers are using GFRP and CFRP, for the upper zone and stirrups are used conventional steel. In the beams are installed LVDT in the middle of beam space and in the point of load application to measure the deflections and deformations. Deformation measurements are installed in the concrete to measure deflection and deformations fig 3. During the test the cracks are measured and the space between them too.

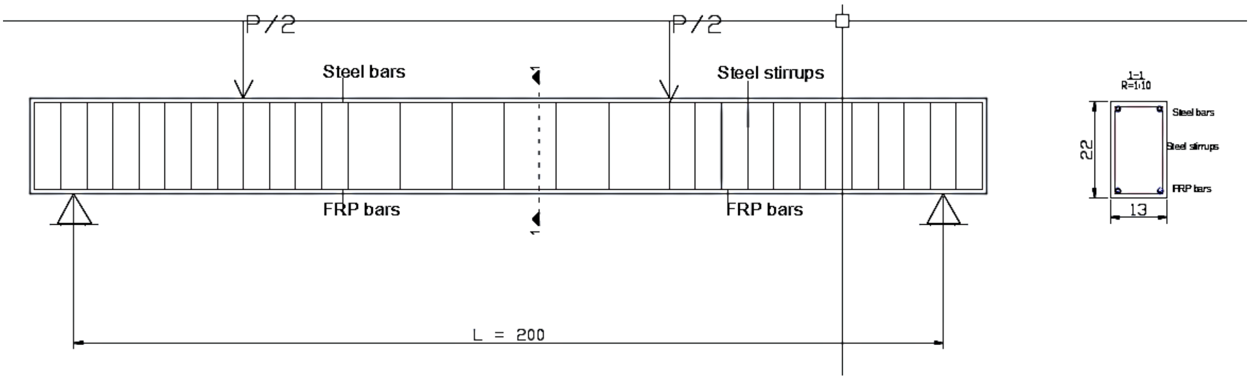

Figure 2. Type of reinforcement used for beams

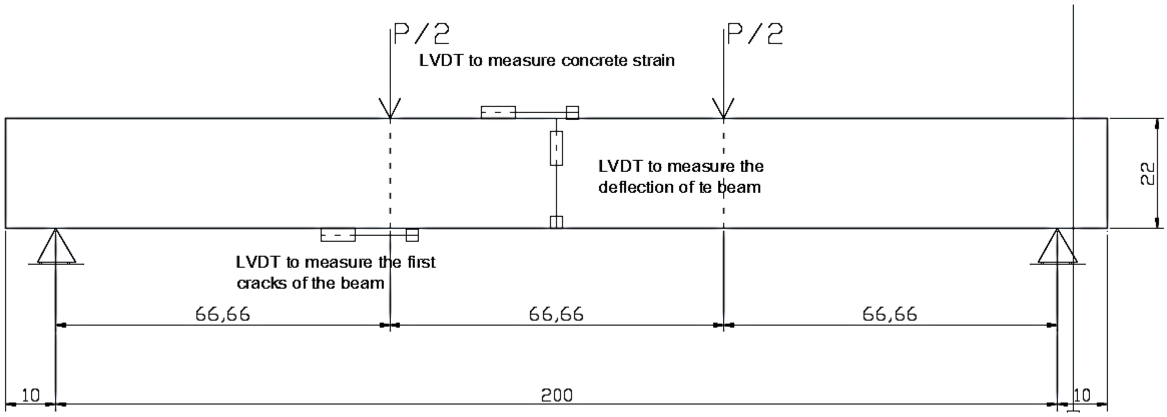

Figure 3. The way of installing the instrumentation LVDT

The concrete mix design is prepared for C30/37 class. In case we want to value the difference between crack width, using 2 methods and comparison with experimental data, we refer to the beam reinforced with 2 bars in 10 mm diameter, for M/Mu =75%. Eurocode 2 gives to us the maximal crack width 1.967 mm and Gergly-Lutz 1,71 mm, modified Gergly-Lutz 1.014 mm and experimental testing 1.739 mm. In the beginning, the beams are cracked in the linear phase of behavior moment-deformation. This is referred to the linear behavior of FRP bars and concrete. The value of "k_b" coefficient is calculated from the formula given by ACI440.1R:

$$k_b = \frac{E_f \cdot w}{2.20 \cdot \beta \cdot f_f \cdot \sqrt[3]{d_c \cdot A}} \qquad (3)$$

From the experimental testing:

1) For GFRP bars with diameter 6mm in SLS design phase, Kb=1,09 and (M/M_u=75%), k_b=1,33
2) For GFRP bars with diameter 8mm in SLS design phase, Kb=1,4 and (M/M_u=75%), k_b =1,68
3) For GFRP bars with diameter 10 mm in SLS design phase Kb=0,7 and (M/M_u=75%), k_b =1,04
4) For CFRP bars with diameter 8mm in SLS design phase, Kb=1,04 and (M/M_u=75%), k_b =0,88
5) For CFRP bars with diameter 10 mm in SLS design phase, Kb=1,03 and (M/M_u=0,75), k_b =1,05

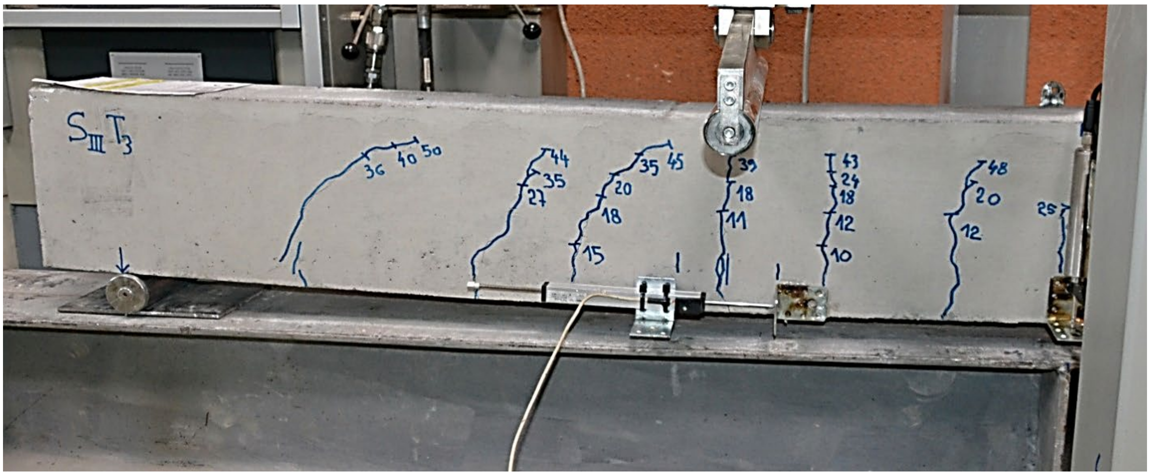

Figure 4. Cracks in the surface of the beam

Conclusions

1. The effect of bar diameter affects in the value of "k_b".
2. In general, the average value of coefficient "k_b" for the CFRP bars is lower than in reinforcement with GFRP bars for the same diameter.
3. Serviceability limit state SLS include the control of the concrete crack width.
4. The value of crack width is depended from many factors, like bond depending coefficient "k_b", protective layer, tensile strength of the bars, concrete strength etc.
5. Beams reinforced with sand coated GFRP bars produce a higher number of cracks and lower width cracks than the beams reinforced with CFRP.

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