Identification of the Influence of Concrete Cover Thickness and Ø/ρ Parameter on Crack Spacing.

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1 Introduction

Cracks in the reinforced concrete (RC) structures create issues to the durability, aesthetic appearance and the liquid or gas tightness of the structure. Among the various types of cracks that can generate in a structure, the cracks due to service load is controlled at the design stage by limiting the calculated crack width. In the most widely used codes of practices (Ex. Eurocode 2, 2004; Model code 2010, 2013; etc.), the calculated crack width is governed by multiplying the crack spacing with the mean strain difference between reinforcement and concrete. Concrete cover thickness and $Ø/\rho_{p,ef}$ parameter (ratio of diameter to reinforcement area to effective tensile area of concrete) have identified as the two most governing factors of the crack spacing model. There are many previous experiments, which have studied about the cracking behavior of RC members. However, with the advancement of material and geometrical properties of concrete and reinforcement, the authors have selected two recent axial tensile experiments to identify the crack spacing governing parameters.

2 The Behavior of Concrete Cover and $Ø/\rho_{p,ef}$ Parameter on Crack Spacing From the Recent Experiments

Table 1 shows the test results of axial tensile experiments of RC ties mentioned in Tan *et al.,*(2018) and Tan *et al.,* (2019). Table 1 confirms that the increase of concrete cover, cause to increase crack spacing and $Ø/\rho_{p,ef}$ parameter does not have a considerable influence on crack spacing.

Table 1. Crack spacing values measured in stabilized cracking stage (Tan *et al.,* 2019).

Specimen No.	Width × height × length (m × m × m)	No. of bars	Diameter (mm)	Cover (mm)	$Ø/\rho_{p,ef}$	$S_{r,mean}$ (mm)	$S_{r,max}$ (mm)
1	0.4 × 0.4 × 3	8	32	40	796	178	240
2	0.4 × 0.4 × 3	8	20	40	1274	163	250
3	0.4 × 0.4 × 3	8	32	90	796	266	320
4	0.4 × 0.4 × 3	8	20	90	1274	217	290

Rimkus and Gribniak (2017) have studied the effect of $Ø/\rho_{p,ef}$ on crack spacing, by keeping the steel area and other crack spacing governing parameters constant. In the study, the different values for $Ø/\rho_{p,ef}$ has been obtained by changing the rebar diameters. The final conclusion of the experiment is that, the crack spacing is independent from the $Ø/\rho_{p,ef}$ parameter. The conclusions of the aforementioned results in Rimkus and Gribniak (2017), gives a good agreement with the statement of Beeby (2004), that $Ø/\rho_{p,ef}$ parameter does not influence on cracking behavior.

3 The Involvement of the Bond-Properties to the Crack Spacing Models.

The author Alander in the discussion paper Beeby *et al.* (2005) made an explanation for why the specimens with low number of larger bar diameter bars and high number of small diameter bars consists with similar crack spacing values. According to their findings, the bond per surface area of every reinforcement is not similar, due to the different rib geometry. Moreover, when the diameter of a bar increases, the bond strength increases, due to the increase in rib area and height relative to the smaller bar diameters (nominal bar diameter to rib height is generally used as 22). Contradictory, from a literature survey it could identify that the bond strength and stiffness decrease with the increase of bar diameter. This leads to a main unanswered question, whether the Rilem-type pull-out or push-in tests represents the bond-behavior of an RC tie subjected to axial tension or flexure.

From the existing literatures, it could identify that the bond-slip behavior in Rilem-type pull out tests are not applicable with bond-slip behavior of the RC ties subjected to pure tension. The experiment mentioned in Beeby (2004), contributes to the fact that, slip does not occur between reinforcement and concrete interface in axial tensile members. A layer of grout is applied at the end faces of RC tie (faces perpendicular to reinforcement), and observed no cracks in the reinforcement-concrete interface after the tensile load is applied. In axial tension, the obtained slip value can be identified as negligible.

4 Conclusions

From the recent experimental results, it could be identified that the concrete cover thickness has a significant effect on crack spacing. However, the $\emptyset/\rho_{p,ef}$ parameter, which present in the crack spacing model due to the 'bond-slip theory' has an negligible influence to the crack spacing. Moreover, it is vital to investigate the applicability of Rilem-type pull-out test results to study the bond behavior in a RC tie. The main contradiction is the, obtained slip value in axial tension is significantly smaller than Rilem-type pull-out tests. Further, from the mentioned facts and evidence it can be confirmed that the slip in axial tension can be considered as negligible. It can be concluded that the mentioned crack spacing models have overestimated the effect of bond-slip behavior.

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