Experimental and numerical study of bond response in structural concrete with corroded steel bars

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Summary

Corrosion can affect the bond between reinforcing bars and concrete and hence the transfer of longitudinal stresses. Although a number of experimental studies on bond failure have been conducted in recent years, the findings have diverged rather widely, due primarily to differing test conditions.

The present paper reports on an experimental programme consisting of eccentric pull-out tests run on corroded steel bars in specimens subjected to accelerated or natural corrosion [1]. An axisymmetric bi-dimensional FE model with finite deformations initially developed to study bond mechanics with sound steel bars [2], has been enhanced to consider bond effects in corroded steel bars. The model simulation is compared to some of the experimental results for corroded and sound bars and the findings are analysed.

Keywords: reinforced concrete, bond, corrosion, tests, eccentric pull-out, finite elements (FE), modelling, corrosion, fibre optic sensors.

1. Introduction

In the present study eccentric pull-out tests were conducted on specimens subjected to accelerated or natural corrosion to study bonding in structural concrete with corroded steel bars. The experimental procedure and the results are discussed in the paper. Moreover, numerical analysis with an axisymmetric bi-dimensional FE model was developed to analyse bond effects in corroded steel bars and its findings were compared to some of the experimental results.

2. Experimental programme

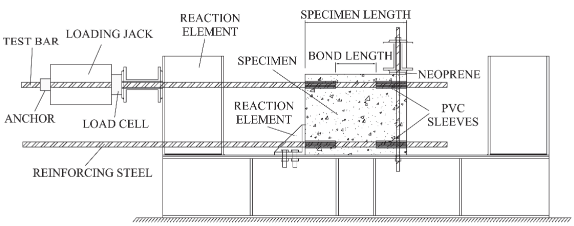

Fig. 1: Test set-up

The choice of the most suitable specimen type is of key importance in bond strength evaluation, as it significantly influences the bond mechanism.

The eccentric pull-out test used in this study is shown in Figure 1. Several advantages of this type of bond test over others had prompted to select the eccentric pull-out test: reproduces bond stress situations more similar to those of found in real structural members; it can reproduce bond splitting failure; it delivers four test results per specimen and allows for direct comparison of the results by bar casting position, i.e., top (T) and bottom (B); and it can be conducted with different types of confinement.

Eight specimens with a 400x400-mm cross-section were prepared for this study, three measuring

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500 and five 600 mm long. Two of these were control specimens, not exposed to corrosion; five were cast with nominal degrees of corrosion ranging from 2 to 12 %, and one was exposed to natural corrosion, likewise as a control. To accelerate reinforcement corrosion a galvanostatic procedure was used and for the natural specimen wet and dry cycles were conducted. The degree of corrosion was measured by comparing the loss in weight of the reinforcing steel over the embedment length with the initial bar weight.

Specimens with a 400x400 mm cross-section and 500 or 600 mm long, depending on bar diameter, were used. The concrete specimens were reinforced at the corners with four bars measuring 10, 12 or 25 mm to give concrete tensile ring radius-to-bar diameter (a/ϕ) ratios of 4, 3 and 2,1, respectively. The embedment length-to-bar diameter (L/ϕ) ratio was 11, except in the specimen with stirrups where the ratio was 12 to maintain stirrup spacing. This embedment length was selected to prevent the steel bar from yielding under the pullout load. Two bars were placed at the top and two at the bottom (casting position) of each specimen. To prevent pressure induced by the test set-up and load-side boundary effects from interfering with the results, the bars were protected with an embedded PVC sleeve on both sides of the specimen.

Eccentric pull-out tests were performed for both corroded and sound specimens with a 310-kN loading jack. The loads were applied in several steps at a constant rate of 3 kN/min. Slip was measured with six linear variable displacement transducers (LVDT), three on the loaded end and three on the free end of the specimen. Steel strain was measured at three cross-sections along the embedment length. The data acquisition system used, embedded, corrosion-resistant fibre Bragg grating (FBG) sensors, was described in a previous paper [1].

3. Experimental results

Since splitting is the most likely type of failure in real structures, the specimens in this study were designed to follow that failure pattern. The bond-slip results as well as the failure mechanism resulting from the tests are described in the paper. The findings for the bars tested are shown in terms of normalised bond stress, obtained by dividing the uniform bond stress values by the concrete tensile strength of the specimen, versus slip. Normalized bond stress was used for readier comparison of the findings. The pull-out results for sound bars and for corroded bars with stirrups, with lateral pressure and with neither are shown and discussed.

4. Numerical modelling of bond

In this study, an axisymmetric bi-dimensional FE model with finite deformations, initially developed to study bond mechanics for sound steel bars [2], was enhanced to analyse bond effects in the presence of corroded steel bars. The ribs were explicitly modelled. The axisymmetric simplification was regarded as acceptable to model the concrete tension ring even though not all the model parameters were clearly axisymmetric. For the interface between the steel bar and the concrete cylinder, a contact surface has been defined. Also adhesion has been implemented by means of a non-linear spring.

The expansion of corrosion products was modelled by establishing thermal strain on the steel bar.. This thermal expansion finally is applied as a radial displacement in the concrete surrounding the steel bar and provision was made for oxide layer deformability, concrete cracking and the possibility of corrosion products diffusing into concrete. The numerical simulation agreed well with the observed bond strength in sound bars. The model predictions for maximum bond strength in corroded bars also agreed well with the test findings, although the stiffness values obtained with the numerical model were lower than observed experimentally.

5. References

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