3D Modelling of the bond behavior of naturally corroded reinforced concrete

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Abstract

Corrosion of steel reinforcement causes cracking and spalling of concrete cover which affects the bond; this is a crucial factor in deterioration of concrete structures. Earlier, anchorage tests have been carried out on specimens with naturally corroded reinforcements. In an ongoing study, the focus is given to the modelling of these specimens. The aim is to evaluate the structural behaviour of the tested naturally corroded specimens. The analyses are performed in the FE program Diana. The frictional bond and corrosion models developed by Lundgren and Zandi are implemented in interface elements to model the interaction between the concrete and reinforcements. The preliminary results of the analysis showed differences in the shear crack pattern in comparison with the experiments. In the analysis, a longer remaining anchorage length was obtained in comparison with the experiment which resulted in a wrong failure mode. The issue might be related to the influence of aggregate interlock in FE analysis.

Keywords: FE-modelling, natural corrosion, anchorage, bond behaviour, RC structures.

1. Introduction

Corrosion of steel reinforcement has always been a major issue in RC structures. Study of corrosion effects is essential for a better understanding of the structural behaviour of existing deteriorated concrete structures. The most severe effect of reinforcement corrosion is the alteration of bond properties between the steel and concrete. Volumetric expansion of rust causes splitting stresses along corroded reinforcement which can be harmful to the surrounding material. Generally, the splitting stresses are not tolerated by concrete, and that leads to cracking and eventually spalling of the cover.

Effects of corrosion on bond have been studied by many research groups, see [1] and [2]. Tests of low rated artificial corrosion indicated a relatively close relation to the natural corrosion conditions, however, literature shows that accelerated corrosion methods may still result in superficial bond deterioration and change the anchorage behaviour, see [3] and [4].

In the presented work, modelling of the anchorage capacity in naturally corroded specimens were investigated. Three-dimensional non-linear finite element analysis was performed to describe the anchorage behaviour of a tested naturally corroded specimen. The results of the numerical model was compared with the experimental data.

2. Experiment

The experiments have been carried out at Chalmers University of Technology. The test setup and the test results are described in detail in [5] and [6]. The specimens were extracted from the edge beams of an existing girder bridge with a concrete slab; the edge beams showed different levels of corrosion-induced damage. Based on the damage patterns, the specimens were categorized in three different groups: Reference (R) beams with no visible damage, Medium (M) damaged specimens with only splitting cracks, and Highly (H) damaged specimens with spalling of the cover. One of these experiments (specimen M4) is presented and compared with the FE analysis in this paper. The drawing and a photo of the designed test set-up are shown in Figure 1.

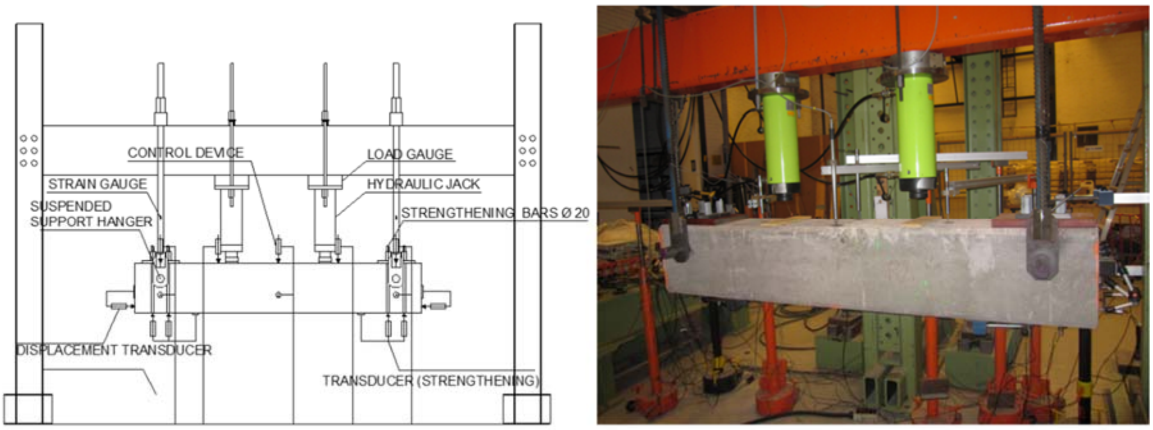

Figure 1 – Photo and drawing of the indirectly supported four-point bending test.

An indirectly supported four point bending test configuration was used for the experiments, see Figure 1. The load was applied by means of two hydraulic jacks defining a central constant moment zone and two shear spans. The beams were suspended by means of a frame which at the same time was used to fix the jacks. The support settlements as well as the mid-span deflection were measured by means of displacement transducers. The end-slip behaviour of the reinforcement bundles was recorded at both ends. The support zones were strengthened to avoid undesirable failure at these locations.

3. FE model

3D non-linear finite element analyses were performed to describe the behaviour and capacity of the anchorage regions. The commercial software DIANA with pre- and post-processor FX+ was used for the numerical simulations. 3D tetrahedral elements were used for both the concrete and the tensile reinforcements. The interface elements were used to model the interaction between the concrete and reinforcements. The frictional bond and corrosion models were implemented in the interface elements. The models used for bond and corrosion were developed by Lundgren [7] and further developed by Zandi [8]. Due to symmetry, only one half of the beam was modelled as shown in Figure 2.

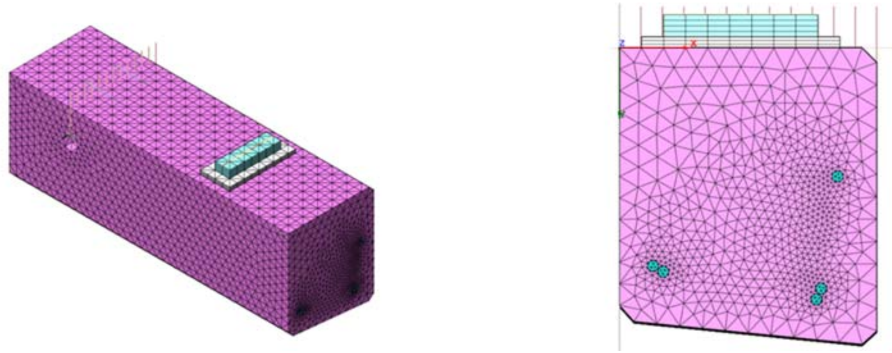

Figure 2 – Overview of the FE model.

The concrete was modelled with a constitutive model based on non-linear fracture mechanics using a total strain based smeared-crack model with rotating crack approach. Thorenfeldt compression curve was used in order to more realistically describe the behaviour of concrete in compression. The reinforcing steel was modelled with an isotropic plasticity model with Von Mises yielding criterion including hardening. The material properties for steel and concrete used in the analysis can be found in [5] and [6]. The analysis were carried out in three phases. In the first phase, the weight of the beam was applied. Then, the longitudinal tensile bars were subjected to corrosion attack in the second phase. The corrosion penetration imposed on the bars were equivalent to 2.93% weight loss measured from the experiment. In third phase, the mechanical load was applied on top of the beam up to the failure.

4. Results

The results from 3D FE analysis, see Figure 3, show a different failure mode than the splitting pull-out failure occurred in the experiment. In the FE analysis, the reinforcement was yielding and the maximum load capacity was overestimated. Moreover, the end-slip was not triggered in the reinforcements.

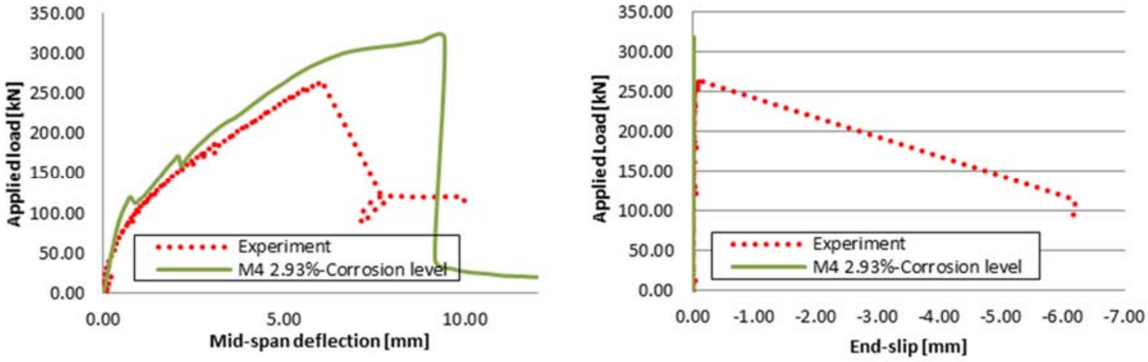

Figure 3 – Results of 3D FE analysis in comparison with the experiment.

The results of the analysis showed differences in the shear crack pattern in comparison with the experiment, see Figure 4. As can be seen, there were two shear cracks in the experiment (marked with numbers 2 and 3 in the figure), while there was only one shear crack in the analysis. Thus, a longer remaining anchorage length was obtained in comparison with the experiment which increased the anchorage capacity and resulted in a wrong failure mode. This issue might be related to the influence of aggregate interlock in FE analysis. For more information, see [9].

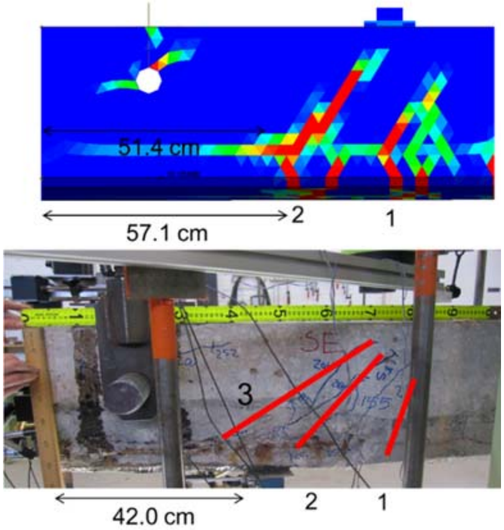

Figure 4 – Comparison of the crack pattern for the beam M4; the remaining anchorage length is given in cm.

5. Conclusion and outlook

Anchorage behaviour of a naturally corroded tested specimen was modelled in detail. The aim was to predict the bond behaviour of naturally corroded tensile reinforcements in concrete. However, the analysis results were deviating from the experiment in terms of crack pattern, end-slip behaviour and failure mode. In continuation, modelling a virtual notch in the concrete geometry will be investigated in order to enhance the behaviour. This solution might trigger the second shear crack in the right location and lead to more realistic results compared with the observations.

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