Anchorage of corroded bars: from cover cracking to cover spalling

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Corrosion process transforms steel reinforcement into corrosion products, leading to (a) a reduction of the cross-sectional area and a change in the ductility of the reinforcement bars, and (b) an expansion of volume that generates splitting stresses in the concrete. The latter effect may eventually crack and spall the surrounding concrete cover and adversely affect the bond between the reinforcement and concrete. The aim of this work is to compute the spalling (delamination) plane in three-dimensional nonlinear finite element analysis and study the anchorage behaviour after cover spalling.

In several research projects at Chalmers, user-supplied subroutines for Diana have been developed to describe the interaction between corroded reinforcement and concrete. A model of corrosion of reinforcement was first developed, where the swelling effects and mechanical properties of the corrosion products are included, see Lundgren (2005). The model has shown to best describe the bond behaviour at/around first cracking, see Zandi Hanjari *et al.* (2011a). Later on, this model was further developed to include transport of corrosion products through cracks, see Zandi Hanjari *et al.* (2011b). This enabled the study of anchorage region for higher corrosion penetration leading to extensive cover cracking. In a recent effort, the model was combined with an external script through a phased analysis to compute the spalling pattern and study post-spalling behaviour of corroded bars in anchorage regions.

In this approach, the analysis starts in Diana with the first phase in which the expansion of corrosion products are imposed in time steps. At the end of each time step, the strain and displacement values of the entire model are tabulated and the width of all cracks developed in the FE model is calculated using and external script. If the crack width is smaller than a threshold value, the analysis is continued in Diana. Otherwise, the spalling pattern is computed using strains and displacements, and a new phase is prepared in which the concrete elements associated with spalled concrete cover are deactivated in the model. The analysis carried out using this approach, shows that not only there is a significant reduction in the bond strength when transforming from cracking to spalling stage, but also there is a fundamental change in the mechanism governing anchorage behaviour. Moreover, there is a further reduction in bond strength after cover spalling with increased corrosion penetration.

Lundgren K. (2005): Bond between ribbed bars and concrete. Part 2: The effect of corrosion. Magazine of Concrete Research, Vol. 57, No. 7, pp. 383-395.

Zandi Hanjari, K., Coronelli, D. and Lundgren, K. (2011a): Bond capacity of severely corroded bars with corroded stirrups, Magazine of Concrete Research, 63(12), 953-968.

Zandi Hanjari, K., Lundgren, K., Plos, M. and Coronelli, D. (2011b): Three-dimensional modelling of structural effects of corroding steel reinforcement in concrete, Structure and Infrastructure Engineering, DOI:10.1080/15732479.2011.607830.