Short abstract "Improvement of the prediction quality of very small crack widths"

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Situation: According to some research results, one expects the reliability of crack width predictions to lessen tremendously for crack widths smaller than 0,2 mm while the uncertainty of the verification increases. Experimental and practical experience exist in which far larger crack widths occurred than predicted despite correct applied verification. This causes in several cases large efforts to rework and close such cracks in structural members, whose design is governed by the DAfStb-Guideline "Concrete structures inflicted by water-endangering substances". Therefore, it was researched why the prediction quality for very small crack widths lessens and how to improve such verifications.

Research program: Using a dataset of the Polytechnic University of Madrid (UPM), we compared currently discussed standard model approaches from DIN 1045-1/MC 90; EN 1992-1-1 and a model that was suggested by the TU Dresden in recent theoretical work. The international dataset contains numerous sets with very small crack widths under varying parameters. A literature study recovered and derived the basic formulas for the first cracking stage controlled by minimum reinforcement. Short tie specimen with notched or prepared crack zones were tested to measure ring deformation on the specimen outside to compare with the Tepfer's-Ringmodel. The deformation between two cracks was also simulated using FEM to survey the influence of lateral strains in the concrete cover on the bond. The analysis of tests on 3000 mm long tie specimens (LDK) produced test data to check the crack width prediction and minimum reinforcement models to control crack widths acc. to DIN 1045-1. The test data from the LDK-tests enabled for statistical verification and model development. A multivariate model and design aids for representative maximum crack widths were based on empirical data in multiple linear OLS-regression.

Results: For small crack widths, it was confirmed that standard approaches, especially DIN 1045-1 approach, inherit large uncertainties for predicting cracks < 0,2 mm. Random and systematic effects as well as artifacts in the empirical background of such approaches cause these uncertainties. Test on short tie specimens showed that negative lateral strains according to concrete tension overlaid the expected surface deformation from bond action. This effect intensifies with increasing cover $c/d_b > 3$. To corroborate minimum reinforcement, the conservative approach MC 90 combined with the DIN strain term provides the most reliable results. The maximum crack width seldom matches the maximum crack distance direct. The product of the depending but unknown sum of bond lengths and the average strain difference between reinforcement and concrete describes the cracks. For calculating the external loading case, a factor on the average crack distance was introduced. It is based on readings and ensures the expected large crack distance simulates the needed large bond length that belongs to the characteristic crack in a structural member with high chance. Connected to the average crack distance definition in DAfStb-Heft 525, it provides a satisfying match of the 95%-percentiles of crack widths for the conducted LDK-tests. An empirical approach based on UPM-data delivered reliable crack width predictions for percentiles of maximum crack widths. A theoretically founded conservative model overtaking the single crack situation into stabilised cracking ensures alternatively against exceeding by maximum test cracks. Stochastic data for concrete strength and the development of crack widths and distances are sampled. This report documents also internal microcracking, crack data and the reading error in visual inspections. For the checked cases of combined reinforcement, the minimum reinforcement verification for steel-fibre reinforced structural members is without problems but longtime influences are still unknown.

Concluding remarks: The reliability of crack width verifications must be increased for cracks < 0,2 mm, for example by using suggested changes. The minimum reinforcement amount should be adjusted to predefined crack widths and 28/56 day-mean concrete tensile strength. This still needs further evaluation in path driven tests on specimens of nearly full-scale size and with practice relevant reinforcement detailing as well as longtime influences. Bond models must be developed further on to cater for the lateral strain effect in tension. Common bond models as MC 90 give to stiff estimates of the bond behavior. The cracking limit state connected to irreversible deformation and durability is still not defined without contradictions. This endangers risk evaluation of hazard scenarios for the environment because of the missing link to probability of endangerment on the side, where the limiting crack widths as design criteria stands, marking an unknown level of capacity or durability.