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Graduate Thesis

Comparison between the results of experimental study on (steel-concrete) bond and of Model Code 2010 regulations

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1. Technological Problem

Steel corrosion degrades significantly the bond between steel and concrete reducing the bearing capacity of Reinforced Concrete (RC) elements. The development of corrosion products (rust) and the drop of steel bars' ribs due to corrosion alter the conditions in steel – concrete interface allowing the relative slip between them and reducing the bond strength. Due to this, the degree of bond strength degradation is of major importance in the assessment of structural capacity of RC members.

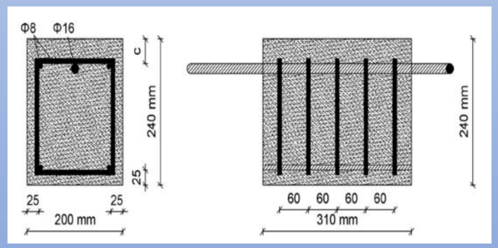
2. Object of Study

The current thesis focuses on the degradation problem of bond between steel and concrete due to corrosion. In particular, simulation of degraded bond mechanism has been conducted developing a finite element model in Abaqus. , The model's validation has been tested comparing with results of the study: "*An Experimental Study on Effects of Corrosion and Stirrups Spacing on Bond Behavior of Reinforced Concrete*".

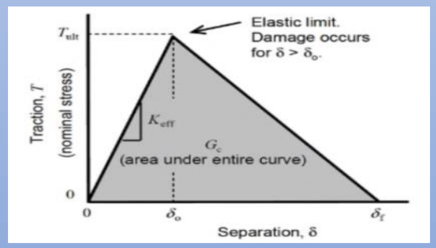
A parallel aim of the thesis was the prediction of the degraded bond strength of corroded RC elements. The study of the existing literature indicated that the different level of confinement through stirrups influences the rate of bond loss. However, the proposals of fib Model Code 2010 do not involve the stirrups spacing in the prediction of degraded bond strength. Due to these, experimental results of the recent literature were collected and divided in four groups in respect to their confinement level: A) Unconfined, B) Slightly , C) Moderately and D) Narrow Confined, respectively. Based on this, a non linear regression analysis was carried out in order to extract degradation laws of bond loss in function with either the corrosion penetration or the average crack width on concrete's surface.

3. Finite Element Analysis and Results

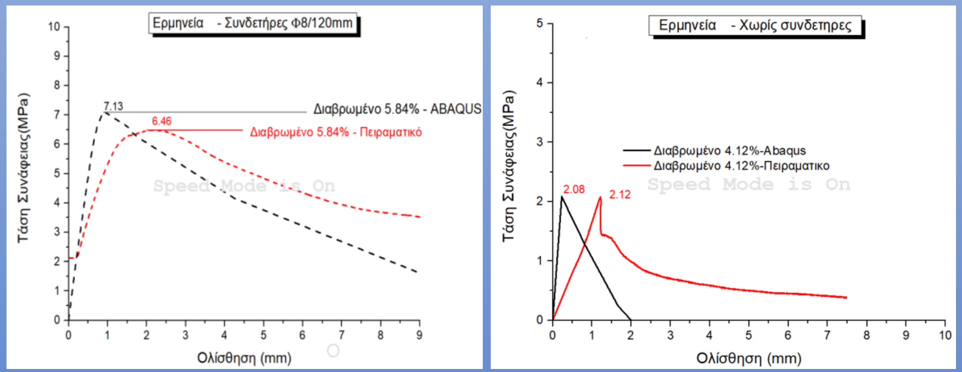
The developed 3D finite element model takes into account the corrosion degradation of the steel – concrete interface and the damage on both materials (concrete and steel reinforcement). Comparison between FE and the experimental results indicated that using surface-based cohesive behavior, which is a mechanical model based on traction-separation behavior, is found to be satisfying for modeling the bond in 3D model of RC members. The proposed bond slip model by Model Code is of a bilinear type, so traction separation law is used to simulate the bond behavior. The main components of this model to be determined from Model Code are the stiffness coefficients in the three directions (Kss, Ktt, Knn) and the slip values of damage initiation and evolution (δ_{init}, δ_{evol}). According to the experimental procedure of the reference study, a non-linear static analysis of a bar pull out test is simulated for the specimens having stirrup spacing of 120mm and for those having no transverse reinforcement.



Picture 1: Geometry of simulated specimens.



Picture 2: Bilinear traction reparation law.



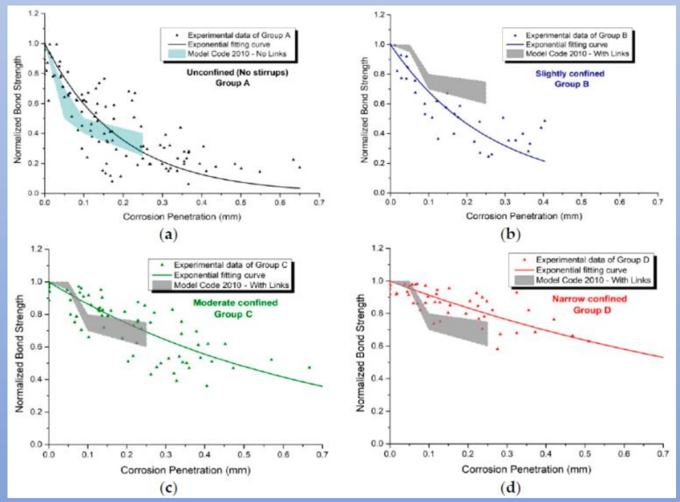
Picture 3: Bond Slip curve for specimen with stirrup spacing 120mm for corrosion level 5.84% (left) and without stirrups for corrosion level 4.12% (right).

4.Regression Analysis and Results

Based on the large collection of test data, among the literature research, experimental values of bond strength with respect to crack width corrosion level and corrosion penetration were gathered and grouped into 4 subgroups based on stirrup spacing. In order to compare the collected database with Model Code recommendations, bond loss values were plotted in every subsequent group and fitted by an exponential function (Picture 5). As a result, degraded laws of bond loss versus corrosion penetration and crack width were extracted for all levels of confinement.

$$\frac{f_{\mathrm{bd,cor}}}{f_{\mathrm{bd,non-cor}}} = e^{-A \cdot c_W} \qquad \frac{f_{\mathrm{bd,cor}}}{f_{\mathrm{bd,non-cor}}} = e^{-A \cdot x}$$

Picture 4: Exponential function used in the regression analysis. *Cw* is crack width value in mm, *x* is corrosion penetration value in mm.



Picture 5: Exponential fitting curves of normalized bond strength as a function of corrosion penetration for groups A (Unconfined), B (Slightly Confined), C (Moderate Confined), D (Narrow Confined) .

Table 1: Parameters from the regression analysis for each group regarding corrosion penetration as a corrosion index.

Confinement level	A	R^2 (%)
Group A Unconfined	5.16	79
Group B Slightly	3.82	80
Group C Moderate	1.47	69
Group D Narrow	0.9	92

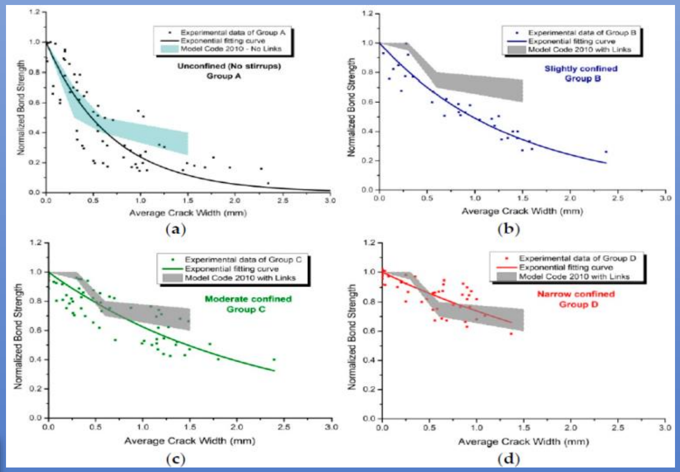


Table 2: Parameters from the regression analysis for each group regarding crack width as a corrosion index.

Confinement level	A	R^2 (%)
Group A Unconfined	1.43	82
Group B Slightly	0.71	92
Group C Moderate	0.47	75
Group D Narrow	0.3	58

Picture 6: Exponential fitting curves of normalized bond strength as a function of crack width for groups A (Unconfined), B (Slightly Confined), C (Moderate Confined), D (Narrow Confined).0

5. Conclusions

From the study 's results as for the finite element analysis we can conclude that bond slip response of the anchored bar can be efficiently predicted with small errors in slip value especially in specimen with no transverse confinement. But further work needs to be done to validate the model with certainty. for the regression analysis, Model Code recommendations are in good agreement with the specimens having no transverse reinforcement in terms of both crack width and corrosion penetration but in overall, the current recommendations need an update. From the noticeable scatter a common way of investigating the bond mechanism needs to be determined.