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Local Bond between Reinforcing Steel and Concrete

Adhérence localisée acier-béton

Lokaler Verbund zwischen Bewehrungsstahl und Beton

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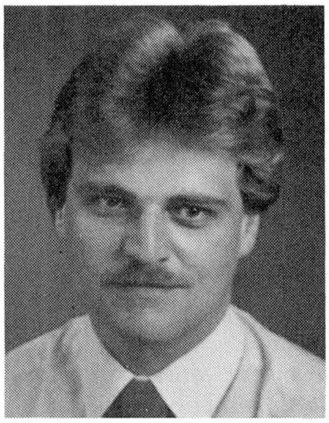

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SUMMARY

Experimental and analytical investigations on the local bond behaviour are presented. The permanent magnet – Hall sensor measuring system was developed for this purpose. This system allows local relative displacements in axial and radial directions between steel and concrete inside the test specimen to be determined. The test results yielded basic knowledge for a better understanding of bond behaviour. Furthermore, a material model was developed which is especially suitable for investigations with the aid of the Finite Element Method.

RÉSUMÉ

L'adhérence localisée acier-béton est présentée à la lumière des recherches expérimentales et analytiques. Grâce à l'emploi de la sonde Hall munie d'un aimant permanent, il a été possible de déterminer les déplacements relatifs locaux dans les directives axiales et radiales apparaissant entre béton et armature, et ceci à l'intérieur-même des échantillons testés. Les résultats du test ont permis d'établir des connaissances fondamentales pour une meilleure compréhension du mécanisme d'adhérence. Un modèle a d'ailleurs été mis au point qui permet d'effectuer des recherches assistées par éléments finis.

ZUSAMMENFASSUNG

In dem Beitrag werden experimentelle und analytische Untersuchungen zum lokalen Verbundverhalten vorgestellt. Mit dem hierfür entwickelten Permanentmagnet-Hallsonden-Messverfahren war es möglich, die lokalen Relativverschiebungen in axialer und radialer Richtung zwischen Stahl und Beton im Inneren der Versuchskörper zu bestimmen. Aus den Versuchsergebnissen wurden grundlegende Erkenntnisse zum besseren Verständnis des Verbundverhaltens gewonnen. Ferner konnte ein Materialmodell erstellt werden, das besonders für Untersuchungen mit der Finite Elemente Methode geeignet ist.

1. INTRODUCTION

Cracks form in reinforced concrete structures when the concrete tensile strength is exceeded. Besides the visible cracks on the surface, inner cracks form at the reinforcing bar ribs. The more the crack formation has progressed, the smaller are the bond forces between steel and concrete. As the crack development depends directly on the concrete strength, the bond stiffness is also influenced by this factor.

The analytical consideration of bond behavior of steel and concrete gains considerable importance. Therefore, the knowledge of realistic models of material behavior is necessary. With these models realistic deformation analyses and economical load-carrying capacity analyses can be executed.

2. GENERAL REMARKS ON THE EXPERIMENTAL INVESTIGATIONS

A detailed description of both experiments and results can be found in [1]. The tension specimens were made of Portland cement PZ35F and natural, unbroken aggregate with a maximum grain size of 16 mm and were centrically reinforced. The following parameters were varied:

- specimen length (short tension specimens without separating cracks of different lengths, long tension specimens with intended separating cracks of different lengths),
- concrete (cover and strength),
- reinforcements (related rib area and diameter),
- loading (number of repeated loads).

For the measurement of the local relative displacements between steel and concrete a small permanent magnet is fixed in the groove of an austenitic reinforcing steel. A Hall sensor is fastened to the concrete at a certain distance to the magnet (see Fig. 1). The magnetic induction influencing the Hall sensor changes with the distance between the measuring system elements. For the determination of the relative displacements a relation between distance and Hall voltage dependent on the magnetic induction is established by calibration before casting. The magnetic induction decreases with increasing distance to the permanent magnet. The relative displacements between steel and concrete at the edge of the specimen were determined using LVDTs.

The forces in the reinforcing steel were determined with the aid of strain gauges glued into two opposite grooves. The bond stress related to one relative displacement measuring point (permanent magnet at reinforcing steel) was analyzed applying the force difference of the strain gauges arranged on both sides of the measuring point.

3. RESULTS

Fig. 1 shows the bond stress - axial displacement relations of two experiments. It can be seen that these relations depend considerably on the concrete strength.

The measuring points arranged at a distance of 35 mm to the edge of the specimen mostly reach the maximum bond stress or even exceed it at the maximum external load of 100 kN. For the measuring points nearer to the center of the specimen (at a distance of 70 mm to the edge of the specimen) the maximum bond strength was reached only with those specimens with a concrete compressive strength of less than 35 N/mm^2 at the maximum external load of 100 kN.

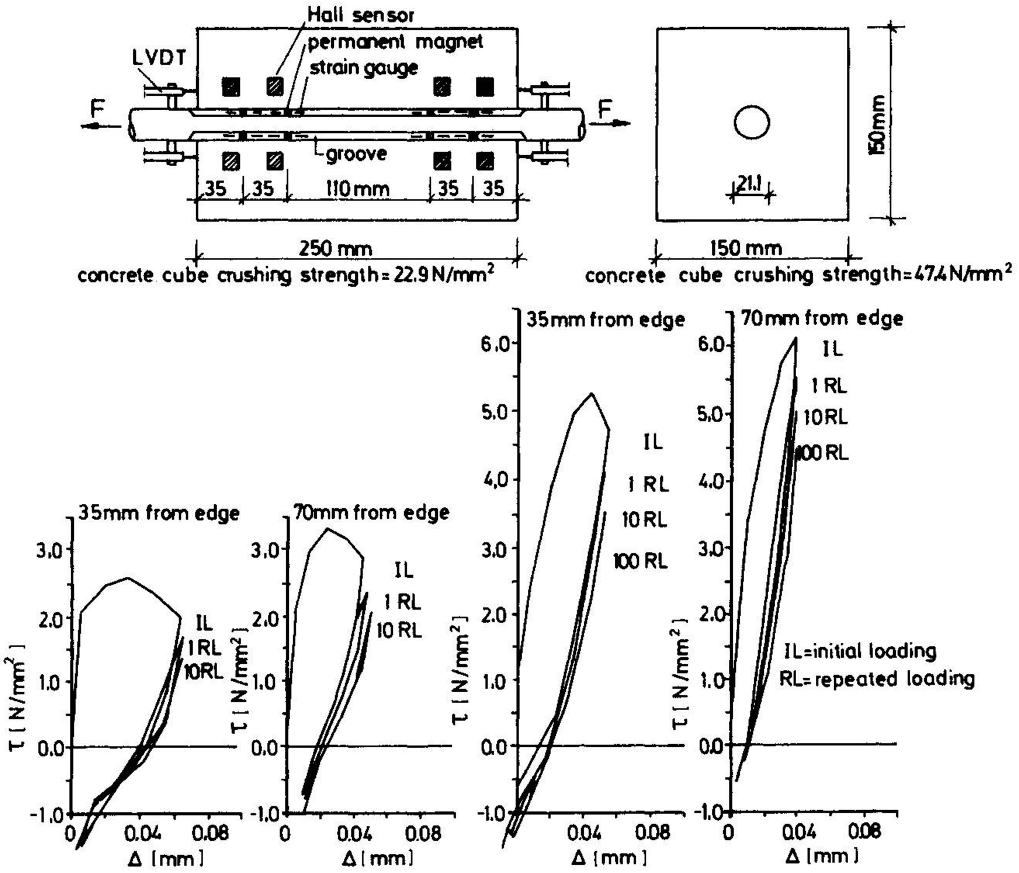

Fig.1 Bond stress - axial displacement relations dependent on concrete strength

An influence of the related rib area on the bond stress - axial displacement relations could not be found. Obviously a certain minimum size of rib area is necessary for the introduction of bond stresses into the concrete. This miminum size at the concrete ribs must be large enough to prevent them from deforming. A deformation of the concrete ribs was not observed with any of the concrete specimens which were split after the tests.

For the determination of the influence of the specimen length specimens which only differed in their lengths (175, 250, and 400 mm) were tested. At equal concrete strength and equal distance to the edge of the specimen smaller bond strengths resulted with increasing specimen length.

Smaller negative or no negative bond stresses occur with specimens with intended cracks contrary to short tension specimens with free edges. This can be traced back to the fact that at a certain unloading of the long specimens an almost constant course of steel stress results. When no external load affects the tension specimens with intended cracks, a nearly constant tensile stress remains in the steel owing to the cracks which do not close completely. Consequently, the concrete is in compression at this point. The intended cracks in the long specimens were arranged in a way that they corresponded to the average crack spacing. This is because the bond stress - axial displacement relations depend on the specimen lengths.

The bond stress - axial displacement relations of long specimens with average crack spacings are decisively dependent on the concrete cover. The larger the concrete cover, the larger the transfer of bond stress between steel and concrete (see Fig. 2).

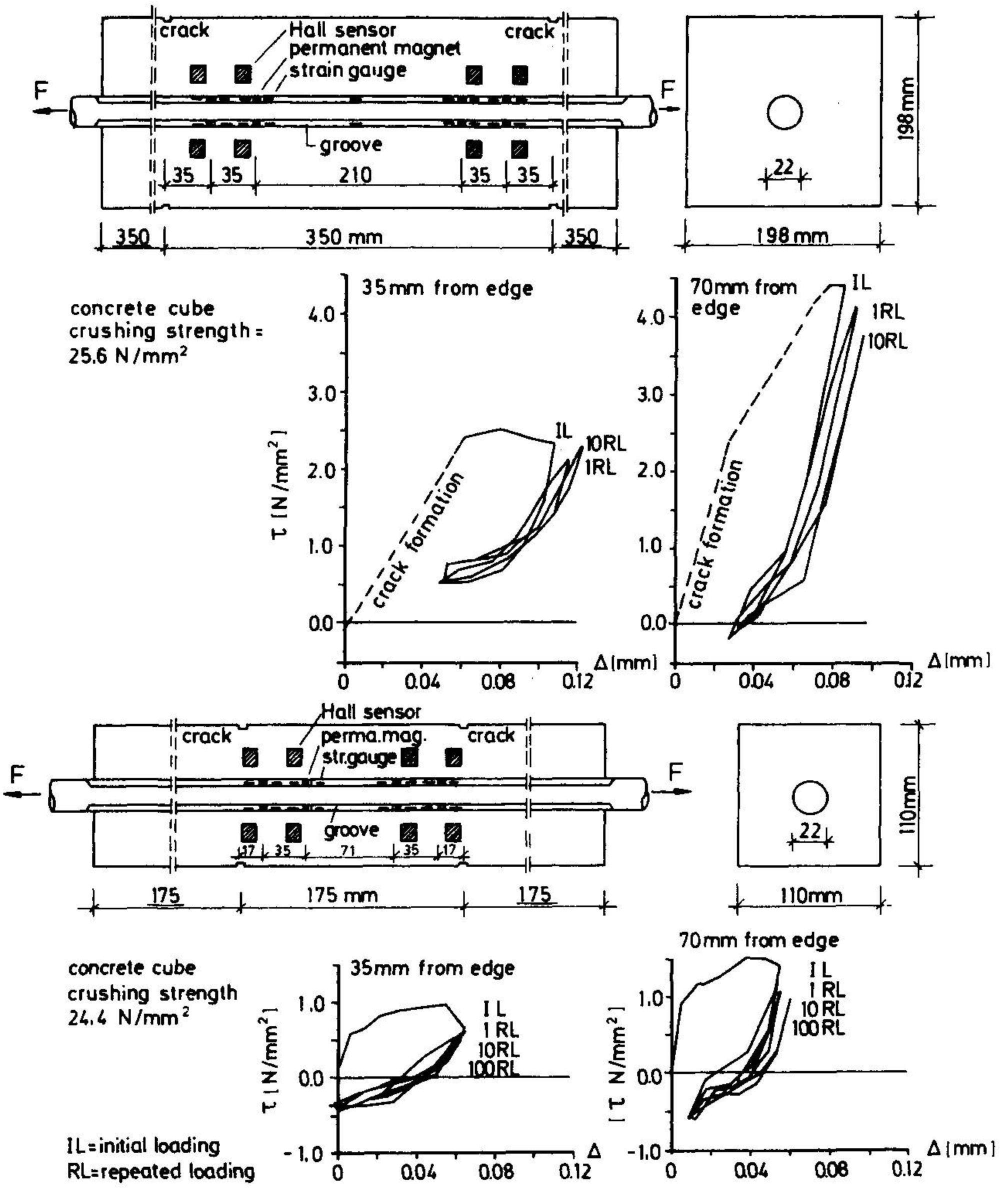

Fig.2 Bond stress - axial displacement relations dependent on concrete cover

For specimens with average crack spacings and a concrete cover of the triple size of differing reinforcing bar diameters the differences of bond stress - axial displacement relations at equal distance to the crack were small. This can be explained by the fact that the relations of concrete cross sectional area and steel surface over which the bond forces are introduced into the concrete have a similar amount.

The courses of relative displacements in radial direction which can be seen in Fig. 3 show that the relative displacements in radial direction at the edge of the specimen increase with increasing specimen length. The relative displacements in radial direction at the edge of a short specimen, however, are larger than those of a long specimen at equal distance to the specimen center. Particularly with the specimens with a length of 400 mm longitudinal cracks form during loading owing to which relatively large relative displacements in radial direction resulted. This explains the lower bond stiffness of edge areas compared to inner areas and the worse bond strength transfer of long specimens compared to short ones at equal distance of the measuring points to the specimen edge.

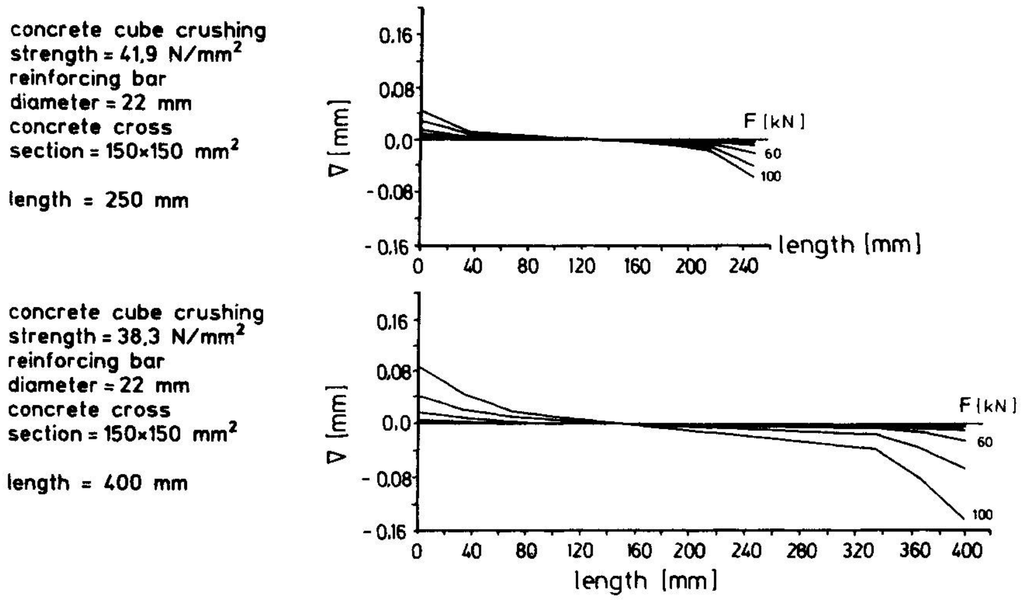

Fig.3 Relative displacements in radial direction dependent on specimen lengths

Fig. 4 shows the relation between relative displacements in axial and radial direction at initial loading. It can be seen that the relative displacements in radial direction are smaller than the relative displacements in axial direction. A distinct increase of relative displacements in radial direction is present only at relative displacements in axial direction of about 0.03 mm or more.

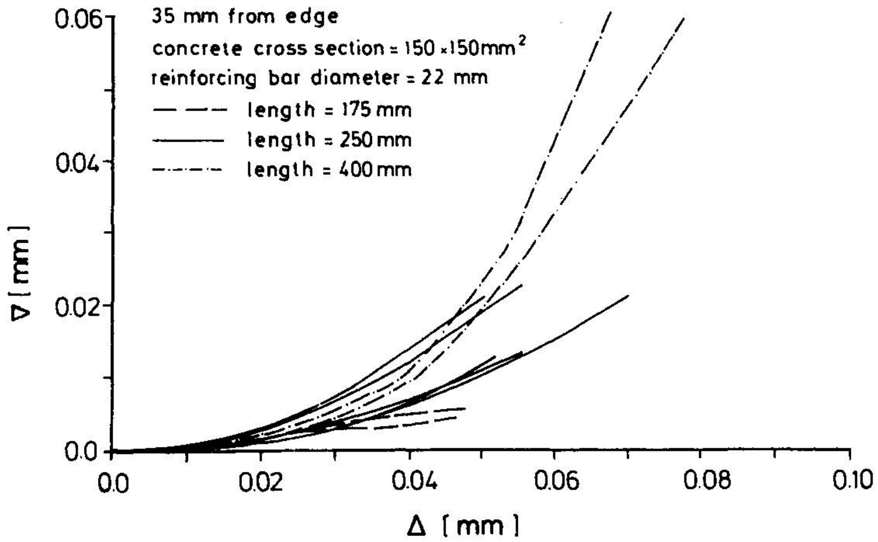

Fig.4 Relation between relative displacements in axial and radial direction for initial loading

4. MATERIAL MODEL

The material model shown in Fig. 5 was determined on the basis of the specimens with average crack spacing. It describes approximately the average bond stress - axial displacement relation between two cracks. The place dependence of bond was not considered as this requires a great deal of additional work in Finite Element analyses. More detailed information for special analyses can be taken from [1].

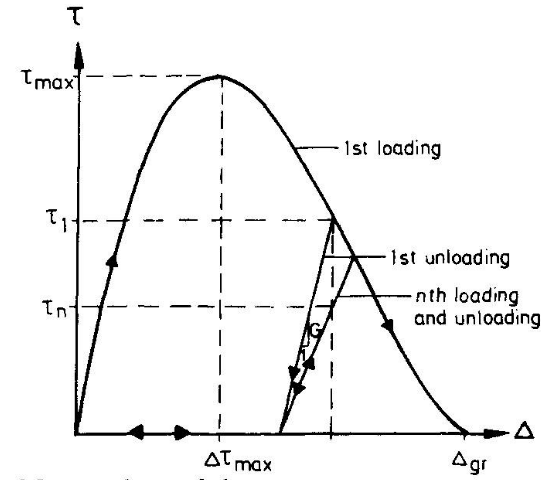

Fig.5 Material model

1st loading

$\tau_{max} = \frac{f_{cube}}{k}$ with

k	c
16	$2 \times d_b$
8	$3 \times d_b$
6	$4 \times d_b$

$\tau = \tau_{max}(4300\Delta^3 - 1000\Delta^2 + 58\Delta)$; Δ [mm]

$\Delta\tau_{max} = 0.04$ mm

$\Delta_{gr} = 0.11$ mm

1st unloading

$\tau = G \cdot \Delta$; $G = 200$ N/mm³

nth loading and unloading

$\tau_n = 0.04\tau_1^2 + c \cdot \tau_1$; τ [N/mm²]

c = 0.65 10th loading and unloading

c = 0.50 100th loading and unloading

5. EXAMPLE FOR THE USE OF THE MATERIAL MODEL IN FINITE ELEMENT ANALYSES

A tension specimen was chosen to demonstrate the use of the material model (see Fig. 6). The calculation was made with the Finite Element Program ADINA which has been enlarged by the contact element [2]. Axisymmetric elements were used for the idealization of the reinforcement and the concrete. The nodes of a concrete element are connected to the nodes of a reinforcement element by a contact element which has no physical dimension in transverse direction. Fig. 6 shows that steel stresses, crack spacings, deformations etc. can be calculate if there are realistic material models.

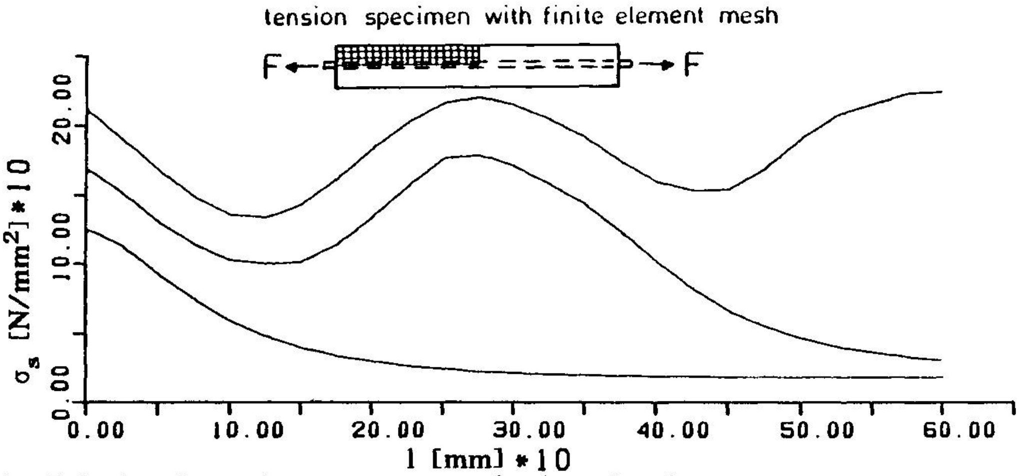

Fig. 6 Calculated steel stresses over the length of a tension specimen

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