BOND DETERIORATION IN REINFORCED CONCRETE MEMBERS UNDER CYCLIC LOADS

by

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SYNOPSIS

The behaviour of intermediate and high strength grade anchored bars supporting a cantilever beam are discussed. Tests showed that under cyclic loading, there is a progressive reduction in the stress transfer capacity between the reinforcement and the concrete. In general, specimens reinforced with high strength reinforcement had a more severe development problem than members with intermediate grade reinforcement. Specimens with intermediate grade reinforcement were generally less stiff in the inelastic region.

INTRODUCTION

Deterioration of bond, or the development of a "soft boundary" around the anchored bars under reversed cyclic loading causes a progressive reduction of the composite action between steel and the surrounding concrete. If this physical phenomenon of bond deterioration can be quantitatively put in terms of a load-slip relationship, then the response of reinforced concrete members can be more accurately determined. The objective of this paper is to examine the behaviour of intermediate grade and high strength grade anchored bars supporting a cantilever beam when subjected to reversed cyclic loading. Results of tests in intermediate grade reinforcement were reported previously (1,2).

EXPERMENTAL INVESTIGATION

The geometry of the eight test-specimens to be discussed is shown in Fig. 1. The beam and end block were cast monolithically to simulate an exterior beam-column joint. Column loads were simulated by applying a constant normal pressure of 1000 psi (7 MPa) to the end block. The length of the end block was selected to insure that a straight length of anchored bar would develop the strength of the 3/4 and 1 in. (19 and 25 mm) diameter longitudinal reinforcement at the face of the end block as per ACI 318-71 (3). Strain guages were installed on the longitudinal bars inside the end block to determine the distribution of stresses along the anchorage length of the bars (Fig. 2). Deflection transducers were mounted ½ inch away from the fixed end to monitor the rotation between the fixed end and the beam. The loading history is shown in Fig. 3. Two variations were used, RV5 and RV10, which correspond to loading between deflection limits of about 5 and 10 times the end deflection at yield respectively. In some cases deflection limits were increased during testing when a number of cycles of loading produced no appreciable change in the response of the specimens (4). Typical stress-strain curves for the reinforcement steel are shown in Fig. 4. Concrete strengths for the eight specimens varied from 5 to 6 ksi (35 to 42 MPa).

GENERAL OBSERVATIONS

(1) Failure Mode: Cyclic loading was continued until failure occurred either by (a) shear stresses disintegrating the concrete near the fixed end or (b) destruction of bond along the longitudinal reinforcement in the anchorage block. Even though only one specimen (3/4 in. bar, RV10 loading) failed because of anchorage block failure, other specimens also exhibited

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bond distress under cyclic loading. Progressive deterioration of bond between steel and concrete was evident from strain measurements which indicated progressively higher strains along the anchored bars with increase in number of cycles. The externally applied load remained either unchanged or decreased with increase in number cycles, as can be seen from typical load-deflection curves in Fig. 5. It is thus not an increase in the load that causes bond distress, but rather the interface between concrete and steel deteriorating through a combination of crushing at both faces of the bar deformations, and splitting of the concrete cover. In addition, with continued cycling, as the concrete at the interface progressively deteriorated, the critical section for moment moved inward along the anchored bar to the point where the concrete was not crushed. The inward shift of the critical section with cycling led to a progressive increase in moment or bar force, and aggravated the anchorage problem.

(2) Stress Distribution in Anchorage Block: Strains in the anchored bars were measured at the peak of every half cycle of loading. Fig. 6 shows the penetration of yield in the anchored top bars at cycle peaks in the primary direction (beam loaded downward, top bars in tension). In general, it may be noted that for the same point on the anchored bar, and a given cycle peak, the stresses are significantly higher in specimens reinforced with high-strength reinforcement than with intermediate grade reinforcement. With 1 in. (25 mm) bars top and bottom, the effect of bar size and load history in influencing the response of the specimen is highlighted by an anchorage failure in the case of RV10 loading history for Grade 60. At the peak of cycle 3, yield was observed at 20 in. (51 cm) beyond the interface (Fig. 6), and the anchorage block showed cracks along its entire length. An attempt to add another cycle of loading resulted in a failure of the anchorage block. Presumably, yielding penetrated to a point along the anchored bar where it was not possible for the remaining anchorage to sustain such high stresses. At failure, large slip of the bars under continued loading then spalled the end cover and exposed the hook end of the bars.

LOAD-SLIP CHARACTERISTICS

As bond between concrete and reinforcement deteriorates, and the length of anchorage becomes insufficient to develop the bar, slip occurs. Slip increases with increasing tension in the bars as the load increases from zero to its peak value at the end of every half cycle of loading. A record of slip measurement, Δ FE, was made by the deflection transducers mounted ½ inch away from the member fixed-end interface. Value of Δ FE includes slip of the bar relative to the concrete as well as bar elongation due to yielding.

Load-slip curves of anchored bars in the primary direction of cycles 1 and 2 are presented in Fig. 7. Note that the curves for Grade 60 reinforcement indicate a stiffer anchorage in the inelastic region than do those for Grade 40 reinforcement. Although yield penetrates deeper into the fixed end for the Grade 60 steel, the elongation may not increase correspondingly. This can be attributed to the shorter yield plateau of Grade 60 reinforcement (Fig. 4). A plot of bar slip Δ FE versus the peak end deflection for cycle one (Fig. 8) indicates clearly the larger slip of the grade 40 steel. The load-slip curves give a measure of the degradation of fixity or softening (bond deterioration) of the fixed end of the cantilever beam under cyclic loading. Quantitatively, the contribution of the slip of anchored bars in the anchorage zone towards the end deflection, Δ ES for a cantilever beam of span L, can be obtained by relating slip to interface rotation Θ FE in the following manner:

$\Delta ES = \Theta_{FE} L$, where $\Theta_{FE} = \Delta FE/h$, h being the center to center distance between top and bottom bars. Using the measured slip values, it was found that the anchored bars contributed upto 60% towards the total end deflection of the beams in some cases.

CONCLUSIONS

Based on these tests, it is difficult to make explicit design recommendations because joint configurations vary greatly between structures. However, the test results provide guidance to the designer for judiciously detailing the joint for a satisfactory performance of the members framing into it.

(1) Development length provisions of ACI 318-71 were not based on data for cyclic load tests, and may be inappropriate for both intermediate grade and high strength reinforcement subjected to reversals of stress in the inelastic range.

(2) With larger bars, severe cyclic loading may produce a brittle joint failure in relatively few cycles of loading. To prevent such failures, it may be necessary to increase anchorage length, increase the confinement for larger diameter anchored bars, or to use a larger number of small diameter bars. If this is not done, the designer should consider the consequence of loss of end fixity on structural performance.

(3) The slip of anchored bars has a significant influence on the response of the member, and cannot be ignored in determining the stiffness or the energy absorbing capacity of the member.

ACKNOWLEDGEMENT

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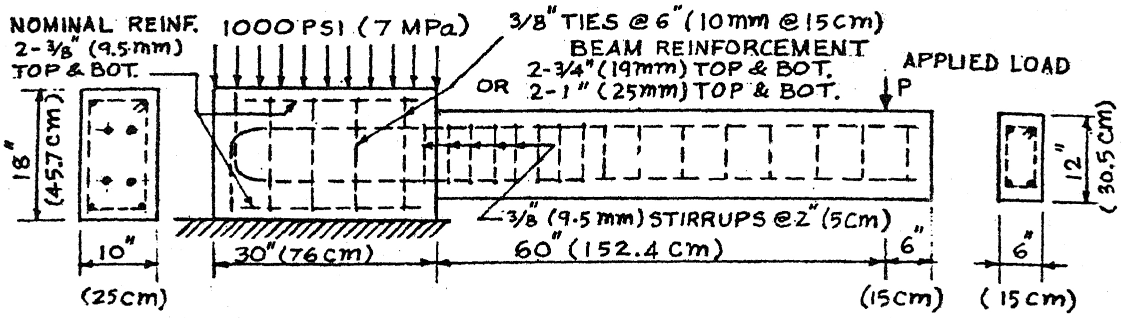

FIG. 1 TEST SPECIMEN

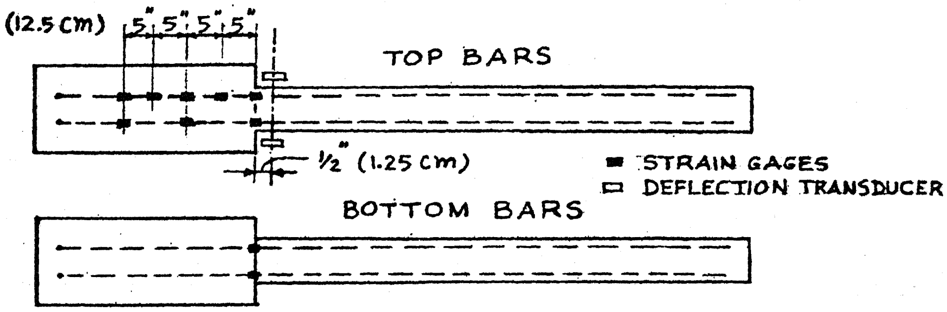

FIG. 2 INSTRUMENTATION

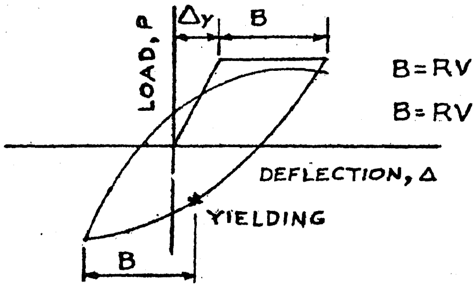

FIG. 3 CYCLIC LOAD HISTORY

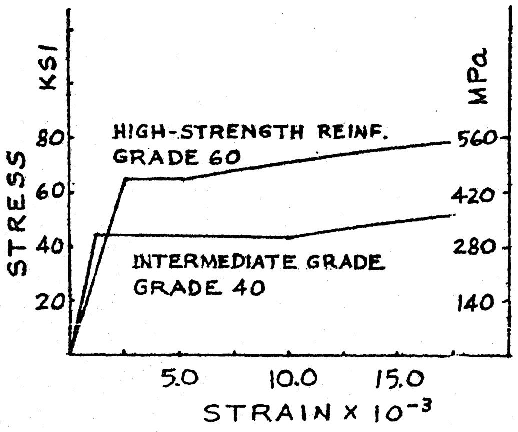

FIG. 4 TYPICAL STRESS-STRAIN CURVES FOR REINFORCEMENT

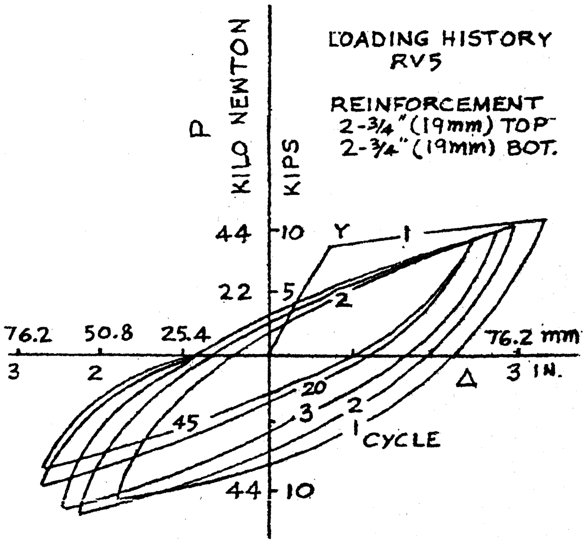

FIG. 5 TYPICAL LOAD-DEFLECTION CURVES

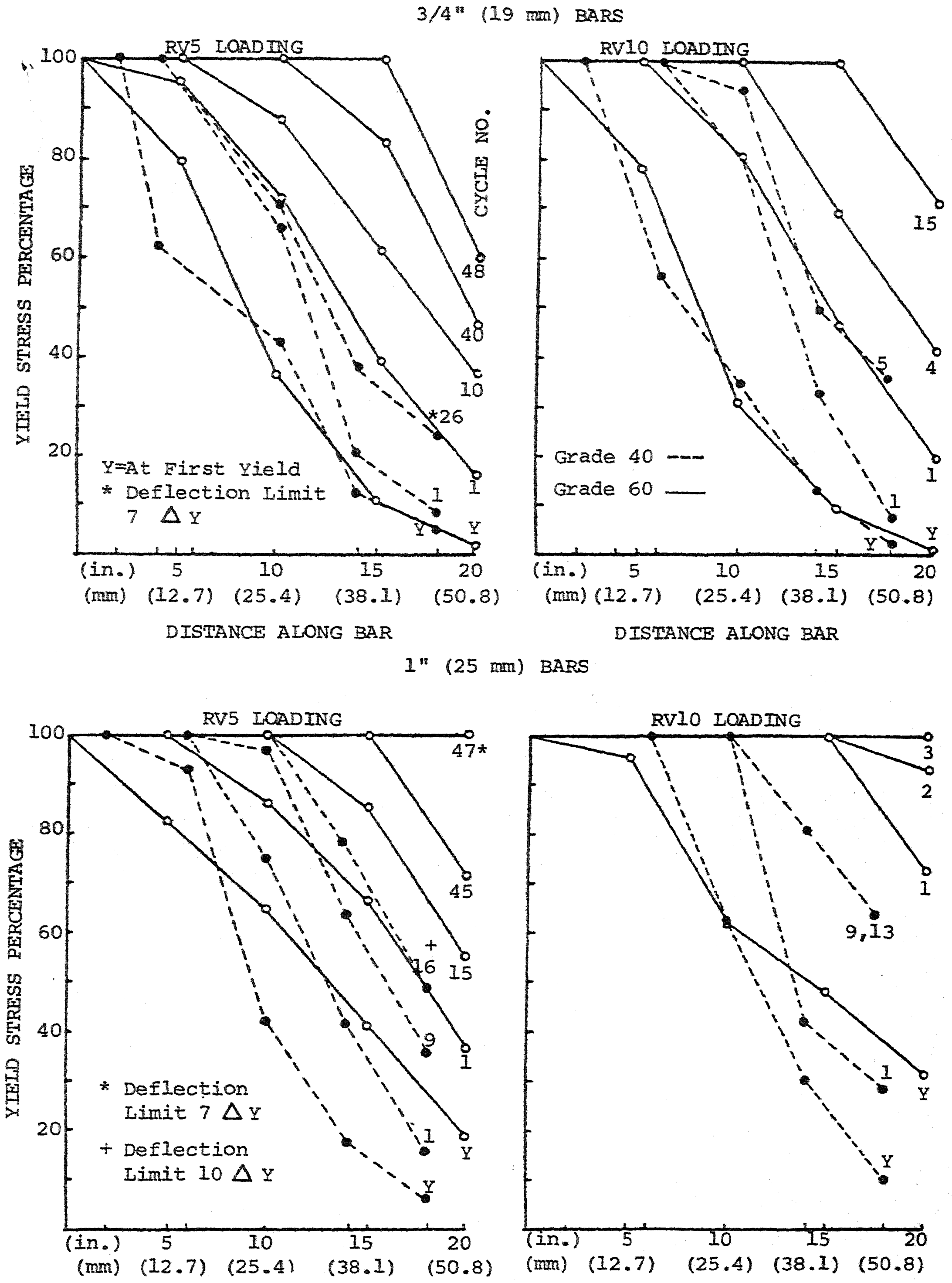

FIG. 6 STRESS DISTRIBUTION IN ANCHORED BARS AT VARIOUS CYCLES OF LOADING

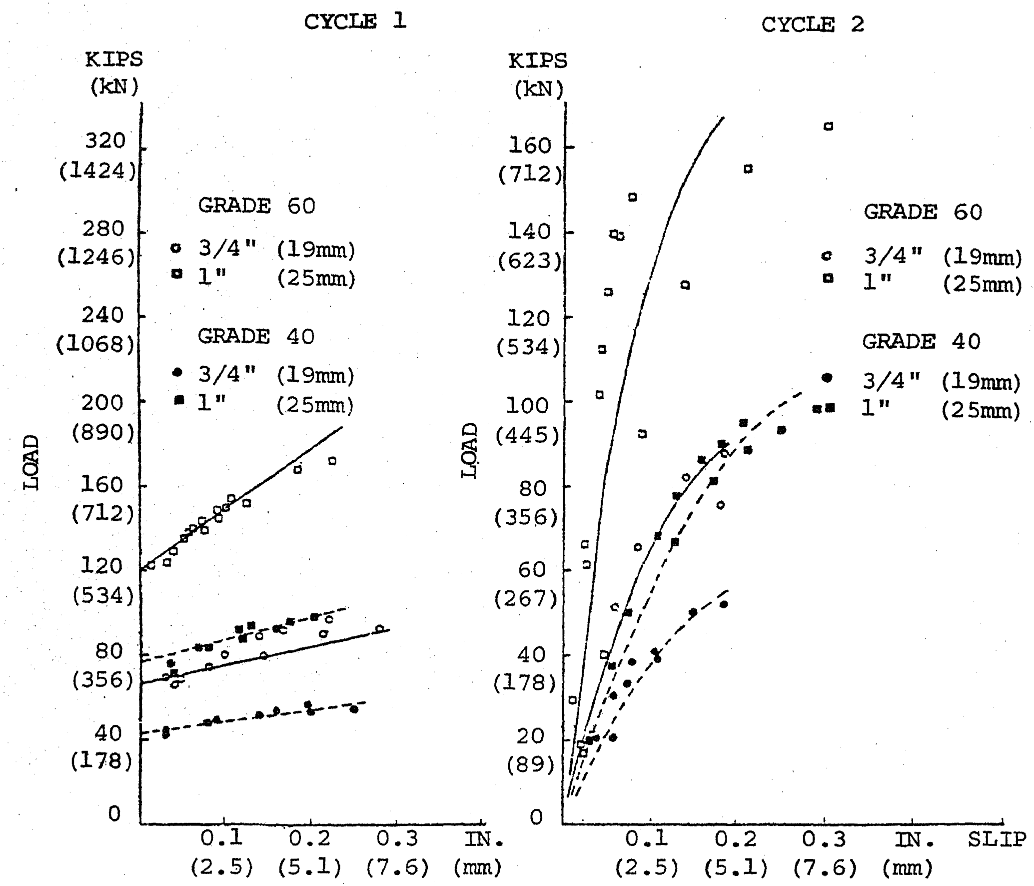

FIG. 7 LOAD-SLIP CURVES

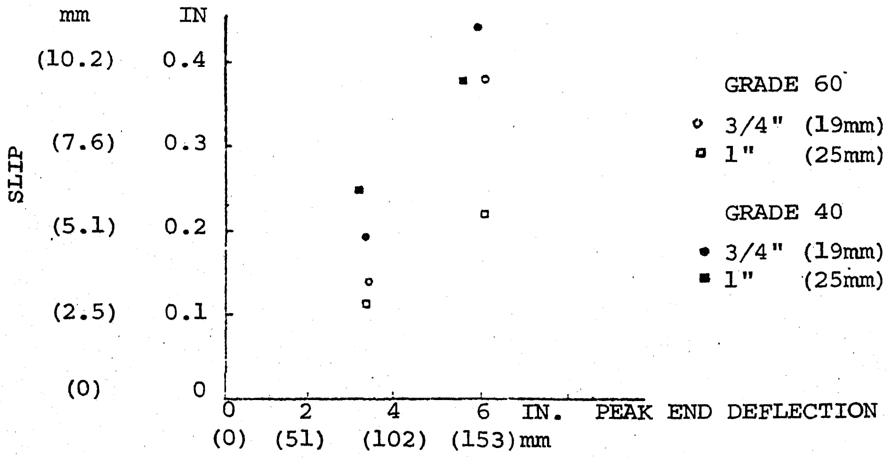

FIG. 8 BAR SLIP VS. CYCLE 1 PEAK END DEFLECTION

DISCUSSION

T. Paulay (New Zealand)

Would the authors comment on the implications of bond deterioration and yield penetration along a flexural bar that is subjected to tension at one end and to compression at the other, while it passes through an interior beam column joint. How is the joint performance affected by loss of bond in the joint ? Can a frame still function if the bar slips through a joint ?

Author's Closure

Not received.