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BOND STUDIES OF DIFFERENT TYPES OF REINFORCING BARS

I - SYNOPSIS

The results of bond tests on one hundred and eighty-eight 6 by 6-in. cylindrical pullout specimens and fifty-one 6 by 12 by 36-in. beams (nominal effective depth 9 in.) containing fourteen types of 1/2, 3/4, and 1-in. reinforcing bars are reported in this paper.

It was found to be impossible to correlate the results of the aforesaid pullout and beam tests. This type of pullout test is a very poor measure of the bond resistance of reinforcing bars placed in beams of the aforesaid dimensions, both in initial and ultimate end slip. It was found that the type of bar has a marked effect on the resistance of bars subjected to a pullout test, whereas, with the exception of screw thread and smooth bars, the type of bar has only a slight influence on the bond resistance of the bars embedded in beams; that a similar strength increase of the concrete causes a greater increase in initial slip resistance of bars in beams than in pullout specimens; that increasing the concrete strength does not result in a very large increase in bond resistance both in beam and pullout tests; that the initial slip in the beams occurs at a much greater calculated bond stress than the initial slip in pullout tests; that the pullout test may give erroneous comparative results in some instances; that most commercial bars are barely

one-quarter stronger than plain bars in bond resistance as determined by beam tests; that twisting two bars together does not increase their strength in bond resistance whatsoever; that generally, the pullout test should be used only in a very broad qualitative manner (if it should be used at all) and that it would be advisable to study the bond behavior of reinforcement in beams, rather than in pullout tests.

II - INTRODUCTION

In reinforced concrete construction, bonding of concrete to steel is of prime importance, for without it the interaction of concrete and steel cannot be obtained. Notwithstanding its importance, there appears to be a tendency to treat the problem of bond with indifference. It is surprising, for instance, that definite, available bond data on various types of commercial reinforcing bars now on the market are lacking.

Present code specifications base the permissible bond working stresses of reinforcing bars on the ultimate compressive strength of the concrete in which they are embedded; the permissible working stress of plain bars is four per cent whereas the permissible working stress for deformed bars is five per cent of the ultimate compressive strength of the concrete.

A deformed bar is vaguely understood to be one which has a bond resistance twenty-five per cent in excess of that of a plain bar. The Progress Report of the Committee on Standard Specifications for Concrete and Reinforced Concrete, January 1937, recommends that deformed bars, to be acceptable, should develop an increase of twenty-five per cent in bond over a plain bar at an end slip of 0.01 in. in pullout tests. Obviously, this may lead to difficulties, depending upon the type of plain bar with which comparison is made. A slightly rusted or roughened bar, for example, should offer a greater bond resistance than a smooth bar; also, modern manufacturing methods tend to impart a smoother finish to plain bars, so that present tests may not be comparable to older tests. Consequently, the variation of bond resistance of plain bars may be considerable, depending upon slight surface irregularities and method of manufacture. Therefore, it seems that the recommendation of the aforementioned committee is inadequate.

Most of the literature relative to bond resistance of bars places special emphasis on initial slip of pullout tests made to a large extent with plain bars, wherein initial slip probably is important. Too little bond data are available for deformed bars, where initial slip may not be as significant as in plain bars.

The consensus of engineers relative to deformed bars is aptly expressed by Professor Abrams* as follows:

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* Bulletin No. 71, University of Illinois

> "The use of deformed bars of proper design may be expected to guard against local deficiencies in bond resistance due to poor workmanship and their presence may properly be considered as an additional safeguard against ultimate failure by bond. However, it does not seem wise to place place the working bond stress for deformed bars higher than that used for plain bars."

It seems desirable therefore, to investigate whether test data on present day reinforcing bars justify present specifications wherein the permissible working stresses for deformed bars are twenty-five per cent in excess of the working stresses for plain bars.

The matter of increasing the permissible bond working stresses is becoming increasingly important. With the introduction of higher steel working stresses, it is essential that the bond stresses be increased proportionately (providing it is safe to do so, of course) in order to make the use of higher steel working stresses economical. Obviously, a higher tensile working stress causes a reduction in steel area, and for a constant bar size, a reduction in the perimeter, which must be offset by increasing the permissible working stresses (or increasing the number of bars, of course). Some engineers advocate the use of stronger concretes to increase the permissible bond working stresses, the general belief being that a stronger concrete should offer proportionately higher bond resistance. This belief has not as yet been fully substantiated by experimental data.

The question of type of bond test to be used in controversial. Two of the prominent early investigators* disagreed upon the pullout test being a measure of the bond resistance of the bars. Abrams believed that pullout tests could be used as a measure of the bond resistance of bars, whereas Withey indicated that the results of the pullout tests did not correspond with the values obtained by testing the bars in beams. At the present time the prevalent opinion is that a pullout test is a fair measure of the bond resistance of bars, although data are not conclusive.

The type of deformation on reinforcing bars probably is also very important. The question whether bars with longitudinal, transverse, diagonal or twisted deformations are superior to plain bars should be studied, and it should also be determined whether there is a great discrepancy in the bond resistance of various types of deformed bars.

This investigation was undertaken to study the following questions:

1. Does the type of deformation affect the bond resistance of reinforcing bars?
2. Is there an essential difference between the bond resistance of various types of commercial bars?
3. How does the strength of concrete affect the bond resistance of reinforcing bars, especially at small end slips?

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* Abrams,, Bulletin No. 71, University of Illinois
Withey, Bulletin No. 321, University of Wisconsin

4. Do pullout tests give a fair indication of the bond resistance of bars at small end slips? (that is, is there a similarity between the bond-slip curves of pullout and beam tests?)
5. Are present bond specifications justified?

III - OUTLINE OF TEST PROGRAM

The test program comprised three series which overlapped considerably.

In one series the effect of the strength of the concrete on the bond resistance of the reinforcing bars was studied. Five concrete strengths, varying from approximately 3000 to 7000 p.s.i. were used.

In the second series the bond-slip pullout and beam curves of nine types of bars used (3/4 and 1-in. in diameter) were compared to determine whether the bond resistance offered by various types of bars was uniform, or whether there was a great discrepancy in the bond resistance. The transverse, diagonal, longitudinal and twisted types of deformations were investigated.

In the third series the bond-slip curves of the reinforcing bars in beams were compared with the bond-slip curves of identical bars embedded in the same strength concrete subjected to pullout tests.

The outline of the test program is given in Table I.

IV - MATERIALS, METHOD OF MANUFACTURE, AND TESTING

All the materials used in this investigation, except the sand and gravel, were donates; the steel bars by the Carnegie-Illinois Steel Corporation, Republic Steel Corporation, Bethlehem Steel Company, The Franklin Steel Works, and Jones & Laughlin Steel Corporation, and the cement by the Lehigh Portland Cement Company.

The coarse and fine aggregates used in the concrete were Portland gravel and Portland sand, respectively, from Portland, Pennsylvania. The coarse aggregate was so combined as to contain fifty per cent, by weight, No. 4 to 3/8-in. and fifty per cent 3/8 to 3/4-in. The fine and coarse aggregates were combined in the ratio 2:3. In designing the concrete, the cement-water method of proportioning was adopted; the water content per cubic foot of concrete was kept constant. Fig. 1 indicates the straight line relation between the strength of concrete and the cement-water ratio for the cement used in the investigation.

Twelve types of 3/4-in. bars (including two types of twisted bars having an area of 0.40 sq in. as compared with 0.44 sq in. area of the 3/4-in. bars, and three types of threaded bars) six types of 1-in. bars, and three types of 1/2-in. bars were used in the investigation. The various bars used are shown in Fig. 2. The popular commercial brands included bars with transverse, longitudinal, diagonal, double diagonal and twisted deformations; plain bars were also included. The twisted bars were manufactured at the Fritz Laboratory in a torsion machine. One complete twist was induced every twelve and one-half diameters of the bars.

The threaded bars were made with the following types of threads:

1-in. bars - 4 square threads to inch, 1/8-in. deep, 3/32-in. wide.

1-in. bars - 9 V-threads to inch, 1/8-in. deep.

7/8-in. bars - 9 V-threads to inch, 1/16-in.deep.

It should be observed that the diameter at the root of threads of all threaded bars was 3/4-in.

As shown in Fig. 3, four 6 by 6-in. cylindrical pullout specimens and three 3 by 6-in. control cylinders were made for each type of bar and each concrete strength used in the study. One hundred and eighty-eight pullout specimens were made with the steel held in a vertical position. The specimens were filled in three layers similar to the method used in making compressive control specimens. The 3/4-in. bars had an embedment of eight diameters, as recommended by Abrams, whereas the 1-in. bars had an embedment of six diameters.

Two or three 6 by 12 by 36-in. concrete beams (refer to test program) each containing one 3/4-in. bar or two 1/2-in. bars and eight stirrups (refer to Fig.4) and six 3 by 6-in. control cylinders were made for each type of bar and concrete strength investigated. Fifty-one beams were manufactured.

The bars in the beams were held in a horizontal position, 2-5/8 in. from the bottom of the form (making the distance from the center of reinforcement to the bottom surface of the beam 3 in.) and the concrete was placed continuously.

All pullout and beam specimens, and control cylinders were permitted to remain in the forms for one day, whereafter they were stored in the moist room (having a constant temperature of 70 deg. Fahrenheit, and a humidity of 100 per cent) until the age of twenty-eight days, at which time they were tested. Fig. 5 shows pullout specimens in the moist room.

The deformation in the concrete (and hence the deformation in the steel, assuming no slip between the concrete and steel - a logical assumption when the bond stress between the concrete and steel is zero for live load) was measured along two gage lines ten inches in length located three inches from the bottom surface, one on each side of the beam.

The end slip in the bars of both pullout and beam specimens, and the concrete deformations were measured by means of Ames dials reading to ten-thousandths of an inch.

The beams were loaded with two equal loads, placed nine inches from each support, and the end slip was measured at both ends of the bar.

The pullout specimens were tested in a 50,000-lb. Riehle screw machine at the rate of 0.05-in. per minute, as shown in Fig. 6. All specimens were placed on a spherical