BOND CHARACTERISTICS OF COMMERCIAL AND PREPARED REINFORCING BARS

by

S. T. Collier, Materials Engineer

(Prepared for presentation by L. E. Gregg, Associate Research Engineer, at the 43rd Annual Convention of the American Concrete Institute, Cincinnati, February 25, 1947)

INTRODUCTION

Early in 1945 a request was made by the Bridge Division of the Kentucky Department of Highways that bond characteristics of certain reinforcing bars be analyzed by the Department's Materials Research Laboratory. Nothing extensive was contemplated, it being the intent of the Bridge Division to determine whether reinforcing steel commonly used on bridge projects at the time would develop bond stresses reasonably close to those that could be developed by the specially prepared bars; and if not, whether the special bars produced benefits commensurate with increased costs.

Five types of bars were selected, and pull-out tests in preference to beam tests were chosen, largely as a matter of expediency. Variable slumps were included but subordinated since structural concrete in Kentucky specifications is limited to 2-inch to 4-inch slumps for most of the heavily reinforced sections in which bond characteristics would be of concern. Unfortunately, at that time, suitable means for vibrating the concrete were not available in the Laboratory for there again the experimental condition did not conform strictly with specification requirements.

Initially, a fairly large variety of tests were planned, but by the fall of 1945 more urgent research on matters pertaining to pavement designs for an expanded construction program made curtailment of the project necessary. Even so, the study served its primary purpose very well, and revealed new relationships and new problems that probably were more important than those originally conceived. As such, these carry a high priority on the list of subject matter for investigation when problems of immediate consequence in design, construction and maintenance have been solved.

MATERIALS

Concrete materials for this study were obtained from sources that normally furnish large quantities for bridge construction in the eastern and central portion of the state. The standard brand of portland cement purchased in a large lot for a bridge construction project was used throughout the tests. Fine aggregate
was a pit sand furnished by a commercial producer north of the Ohio River, the source of material here being a glacial terrace in conjunction with the valley of a major tributary to the Ohio. Coarse aggregate was crushed limestone of the standard Kentucky size No. 6 (90 to 100 percent finer than the 1-inch size and 0 to 10 percent finer than the No. 4) obtained from the stockpile of a producer. Geologically, the limestone was lower Ordovician of the Tyrone and Oregon formations—a dense crystalline material low in impurities principally silica in the form of stable quartz. The stone had an excellent service record in concrete for all purposes.

Tests of the cement by the Testing Laboratory passed this material for use, and tests of the aggregates by the Research Laboratory showed that fine (sand) and coarse (stone) materials had a bulk specific gravity of 2.65 and 2.72 respectively, and similarly absorptions of 1.0 and 0.6 percent. In addition, the limestone had a Los Angeles Abrasion loss of 27 percent.

Four of the five types of reinforcing bars—all 7/8 inch in diameter and 36 inches long, all deformed, and all of what is generally called intermediate grade reinforcing steel—were obtained directly from the manufacturers. Three of these were "specially prepared", the deformations being in the form of ribs rather than lugs. All of the three specials were similar to the extent that ribs in each case formed a closely spaced double helix, but differences lay in the form and spacing of ribs.

FIRST SLIDE

Briefly, the special bars, as indicated in Fig. 1, had:

Bar No. 1—Continuous double helical ribs spiraling continuously around the bar at 0.4 inch spacing.

Bar No. 2—Reversed double helical ribs spaced at 0.4 inch, the direction of the helix on one side of the bar being reversed with respect to that on the other side.

Bar No. 3—Same deformations as Bar No. 2 but spaced at 0.5 inch.

In contrast, the fourth bar purchased from a manufacturer was a so-called commercial type having transverse lugs spaced 1.5 inches apart and staggered on opposite sides of the bar. This specimen was designated as Bar No. 4.

The final type, referred to as Bar No. 5, was also of the "commercial" group and was purchased from a local supply house in Lexington. This bar had longitudinal lugs spaced at 4.0 inches in each of four rows, the lugs being staggered directionally rather than at 90 degrees. It is pertinent but of undetermined significance that all bars purchased from the manufacturer were new, in good condition, and had little or no rust; whereas specimens of
Bar No. 5 were completely covered with rust when purchased, the rust being removed with a wire brush before the bars were used. Tension tests on the different bars checked closely the manufacturer's certification of a yield point of 42,000 pounds per square inch.

PROCEDURE

The bars were cast in three positions in a manner illustrated by Fig. 2, and all were embedded to a depth of 10½ inches or 12 diameters.

SECOND SLIDE

Those specimens cast vertically were placed in standard 6 by 12 inch concrete cylinder molds with one end of each bar protruding approximately 0.5 inch below the base of the mold. Specially designed bases for this purpose, plus the use of supporting frames and clamps provided means for holding the bars rigidly in place while concrete was poured and set.

Similarly, horizontal bars were cast in upper and lower positions in 6 by 10½ by 18 inch prisms, the upper having 15 inches and the lower having 3 inches of concrete below its center. Again each bar extended about 0.5 inch beyond the back of the mold. Molds for these prisms were wooden with steel clamps, and rigid supports at the front and rear of the forms held the bars in place while the concrete was setting. After the entire prisms had cured for fourteen days, the bars and surrounding concrete were separated into upper and lower horizontal specimens by sawing the prisms on two planes, designated as A and B in Fig. 2. By this procedure separate samples 6 by 6 inches in cross section (with the bars centered in that area) and 10½ inches long were provided, the intervening 6 inches of concrete between planes A and B being wasted.

Batches were designed for quantities sufficient to cast all samples of a series or all those representing a given bar embedded in concrete of a given slump. In all cases, two samples for each type of embedment were prepared, and in addition, three cylinders for twenty-eight day compressive strength determinations were poured. Basic design for the mixes was:

Cement content: 6 sacks per cubic yard
Water: 6 gallons per sack
Proportions of Aggregates by weight:
- 40 percent fine
- 60 percent coarse
Slump: 3 inches

As stated before, some specimens with slumps approximating six inches were made, and in those instances adjustments in design were, of course, necessary.

Concrete was placed in both types of molds in three inch lifts each rodded twenty-five times with a puddling rod and spaded
with a trowel about the outer faces of the molds. The first twenty-four hours of curing was under wet burlap, then the forms were removed and the samples were placed in the moist room. After a total of fourteen days, specimens were prepared for test by sawing the horizontally cast samples from the prisms as previously described, then capping both the compression test cylinders and the pull-out test samples, the former being treated in the usual manner and the latter being capped at the ends where loads were eventually applied. Here care was taken to make the capped surfaces perpendicular to the axis of the bars in order to avoid eccentric loading caused by uneven bearing between the capped surface and the head of the testing machine. An additional period of fourteen days curing in the moist room was allowed before the specimens were loaded.

A 300,000 lb. hydraulic machine with a smallest interval of 100 pounds in the 100,000 pound range was used in making the pull-out tests.

THIRD SLIDE

Each specimen was mounted in the machine by placing the embedded block on a smooth plate set on top of the upper or moving cross head (as shown in Fig. 3) so that the 25 inch unenclosed portion of the bar extended downward. The bar was gripped by jaws in the lower or stationary cross head - 20 inches of the bar remaining between the concrete block and the jaws. An extensometer clamped on the concrete block and consisting of a dial gauge bearing on the bar was used to measure slip at the upper or free end of the specimen. This gauge measured to 0.0001 inch.

Below the moving cross head and fastened securely to the bar was another extensometer consisting of two dial gauges measuring to 0.001 and bearing on the lower surface of the cross head. Average readings of these gauges at any load modified by subtracting pre-determined elongation of the bar at that load was the measure of slip at the loaded end of the bar. Loads were applied at the rate of 1,000 pounds per minute and extensometer readings were taken at each 1,000 pound interval, the test being concluded when the slip at the loaded end reached 0.02 inch. In some cases this resulted in steel stresses greater than the yield point.

RESULTS

Average compressive strengths for the several mixes varied from a low of 4633 pounds per square inch for a mix with a water-cement ratio of 6.70 gallons per sack to a high of 5818 pounds per square inch for a mix having a 5.42 water-cement ratio. Those which had slumps within the range permissible under Kentucky specifications - viz., 2 to 4 inches - did not fall below 5350 pounds per square inch compressive strength. The maximum variation among strengths of three samples representing any mix in this category was 3.0 percent; hence, there is little doubt of the quality and uniformity of mixes from the standpoint of strength.

FOURTH SLIDE
As might be expected, the effects of slump on bond and steel stresses developed in the pull-out tests were more obscure. Typical of this were the relationships plotted for Bar No. 1 in Fig. 4.

FIFTH SLIDE

These data, and those representing commercial bars, indicated that the reaction of bond characteristics to slump was dependent upon the position of casting. Almost invariably, greater stresses were developed by the specimens with lowest slump when the bars were cast vertically; however, the opposite was true for specimens cast horizontally. There were exceptions to this, principally from the standpoint of stresses developed at different amounts of slip.

Ostensibly these relationships indicate that the placing of concrete was quite influential, it being easier to distribute the more plastic concrete about the bars in the case of those cast horizontally; whereas in the case of specimens cast vertically there was little or no difference in ease of placement so the concrete with lowest slump and greatest strength had the best bonding power. Further significance may be attached to the fact that specimens with concrete of different slumps were more nearly equal in bond on bars cast in the upper horizontal than in the lower horizontal positions. This was so despite the pronounced inferiority of bond characteristics for all upper horizontal specimens. These, as well as other results from tests on the five sets of specimens are illustrated in Fig. 5.

SIXTH SLIDE

For all specimens represented, the total lead-slip relationships of bars cast in the upper horizontal position were never equal to those of specimens cast in the other positions. However, in one instance (Series A) the initial portion of the curve did not conform to this pattern, that instance being the only one where the stresses developed by upper horizontal bars closely approached those developed by bars cast in the other positions. Generally, the stresses of the upper horizontal specimens seldom exceeded 60 percent of stress values for other specimens at corresponding degree of slip. Also, for the most part, the bars cast vertically were superior to those in the lower horizontal position, but the superiority of the vertical bars was not as pronounced as the inferiority of upper horizontal bars.

With but one exception, all types of special deformations increased the bond or resistance to pull-out forces, especially in the lower ranges of slip. Only in the specimens cast vertically did the bond of one commercial bar exceed that of a special bar. Furthermore, the resistance of these vertically cast bars was so great that in all but one case (Series C, Bar No. 4), the yield point of the steel was exceeded and as shown in Fig. 6, that point was exceeded with less than 0.01 inch slip for bars No. 1 and No. 3;
and at only slightly more than 0.01 inch slip for bars No. 2 and No. 5. Only No. 3 bar developed a steel stress greater than the yield point when embedded in the upper horizontal position, but all the special bars exceeded the yield point when cast in the lower horizontal position.

All things considered, there was little basis for differentiating among the bond characteristics of the three specially prepared bars for where Bar No. 1 developed the greatest stress in the vertical position, Bar No. 2 exceeded in the upper horizontal position, and Bar No. 3 (except in the very low range of slips) was best in the lower horizontal position. In contrast, the commercial bar with longitudinal lugs (Bar No. 5) invariably and unmistakably surpassed the bar with transverse lugs in bond developed at any amount of slip.

LIGHTS

Within the limitations of the number of tests made, possibilities of experimental error, and inconsistencies of sample preparation, it can be said that:

1. Bonding power varied with the slump of the concrete, but that the variation was largely dependent upon the position in which bars were cast.

2. Bars cast in the vertical position developed greatest bond, those in the lower horizontal position were intermediate, and upper horizontal specimens were distinctly inferior in bonding power.

3. Specially prepared bars in practically every instance developed higher stresses than the commercial bars, especially when the specimens were cast horizontally. Differences were accentuated in the range of low slips since special bars developed high stresses with little movement, while on the contrary, the stresses in commercial bars increased more uniformly throughout the range of measured slips. When the bars were cast vertically the differences between bars of the two categories were not so distinct nor so great.

4. The bonding efficiency of the three prepared bars varied with the three positions of casting so that there was little basis for differentiating among the bars. On the other hand, the commercial bar with longitudinal lugs invariably developed better bond than the commercial bar with transverse lugs.