SUMMARY OF TESTS OF BOND BETWEEN CONCRETE AND STEEL.

THE usefulness of reinforced concrete as a structural material depends on the strength and permanency of the bond between the concrete and the reinforcing metal, and for this reason bond resistance has received much attention from engineers and experimenters. It is said that Thaddeus Hyatt made tests to determine the bond between concrete and iron bars as early as 1876. During the past decade numerous bond tests have been reported. These tests have been characterized by a lack of uniformity in the form of the test specimen and in the methods of conducting the tests, as well as by the wide variations in the values reported for bond resistance. In nearly all the tests thus far published values of maximum bond resistance only have been given. These test results and the discussions called forth by them have furnished the basis for a great variety of opinions as to the value of bond resistance. Many explanations of the source and nature of bond resistance have been given. Various methods have been advocated for increasing bond resistance and numerous devices have been employed for this purpose.

Present practice is fairly standardized as to the bond stresses to be used in designing, but a rational basis for the stresses used is lacking and there is a great diversity of practice in the methods of calculating these stresses. There are many phases of bond action which are not now understood. It is evident that the distribution of bond stress in reinforced concrete members under load and the nature and value of bond resistance under given conditions may well be the subject of experimental investigation.

The tests reported in a bulletin, entitled "Tests of Bond between Concrete and Steel," recently issued by the Enginering Experiment Station of the University of Illinois, were undertaken with a view to securing additional information on the nature of the bond resistance of reinforcing bars in concrete, to determining values of bond resistance for a wide range of conditions, and to studying bond action in specimens of different forms. Tests were made on pull-out specimens and on reinforced concrete beams. In both forms of specimen attention was given to obtaining accurate measurement of the slip of bar through the concrete as the loading progressed. In many of the beam tests the slip of bar at various points along its length was measured for different loads. In the discussion of bond resistance the load-slip-of-bar relation has been utilized to a considerable extent. These measurements are useful in indicating the distribution of bond stress. They are particularly significant in the beam tests. In a few of the beam tests the distribution of bond stress was studied by measuring the changes in the stress in the longitudinal reinforcement throughout the length. The values found for bond resistance and the relative bond resistance found in beam tests and pull-out specimens are also interesting features of the investigation.

The pull-out tests consisted in applying load to a short reinforcing bar embedded in a block of concrete. The concrete block was generally 8 in diam. and 8 in. long, with the bar embedded axially. In certain groups of tests these dimensions were varied. The size of bar used varied between ¼ in. and 1¼ in. The pull-out tests covered a wide range and included effect of dimensions of specimen, effect of form of bar, effect of conditions of storage, effect of age and mix, using both plain and deformed bars, effect of different methods of loading, bond resistance of concrete setting under pressure, effect of reapplied loads, comparison with the bond resistance of reinforced concrete beams, etc. The deformed bars used included most of the forms in use at the time the work was begun, but it should be noted that the tests with deformed bars were intended to bring out the action of the deformed bar as contrasted with the plain bar and not to determine the value of particular forms of bars.

A special effort was made to determine the behavior of beams subjected to high bond stresses. The beams tested were 8 by 12 in. in section with an effective depth of 10 in. The span length was generally 6 ft.; a few beams were tested with span lengths of 5 to 10 ft. All beams were tested with two symmetrical loads, generally at the one-third points of the span. With the exception of six tests, the longitudinal reinforcement consisted of a single bar of large diameter placed horizontally throughout the length of the beam. Both plain and deformed bars were used.

The tests were made in the laboratory of Applied Mechanics of the University of Illinois, and formed a part of the investigations of reinforced concrete and other structural materials which are being conducted by the Illinois Engineering Experiment Station. These tests cover the experiments which were designed with special reference to a study of bond between concrete and steel during the period of 1909-1912. This work was done by Duff. A. Abrams, Associate in Theoretical and Applied Mechanics, under the direction of A. N. Talbot, Professor in Charge of that Department. The tests covered a wide range of conditions and the results have a significant bearing on the nature of bond resistance, the action of bars of different forms under bond stress, and the behavior of beams subjected to high bond stresses. The load-slip determinations have given definite information on the nature and distribution of bond resistance. The following is a resumé of the principal observations and conclusions which have been stated and discussed in the text. Paragraphs 2 to 34 refer primarily to the results of the pull-out tests:—

(1) Bond between concrete and steel may be divided into two principal elements, adhesive resistance and sliding resistance. The source of adhesive resistance is not known, but its presence is a matter of universal experience with materials of the nature of mortar and concrete. Sliding resistance arises from inequalities of the surface of the bar and irregularities of its section and alignment together with the corresponding conformations in the concrete. The adhesive resistance must be overcome before sliding resistance comes into action. In other words, the two elements of bond resistance are not effective at the same time at a given point. Many evidences of the tests indicate that adhesive resistance is much the more important element of bond resistance.

(2) Pull-out tests with plain bars show that a considerable bond stress is developed before a measurable slip is produced. Slip of bar begins as soon as the adhesive resistance is overcome. After the adhesive resistance is overcome, a further slip without an opportunity of rest is accompanied by a rapidly increasing bond stress until a maximum bond resistance is reached at a definite amount of slip.

(3) The true relation of slip of bar to bond stress can best be studied by considering the action of a bar over a very short section of the embedded length. The difficulties arising from secondary stresses made it impracticable to conduct tests on bars embedded very short lengths. The desired results were obtained by varying the forms of the specimens in such a way that the effect of different combinations of dimensions could be studied.

(4) Pull-out tests with plain bars of the same size embedded different lengths furnish data which suggest