value. Their values may be elastic, varying with the temper of the people, rising and falling with the rise and fall of prosperity.

However, in view of the favorable public reaction to reducing travel time it is important to arrive at acceptable values in order to take the fullest credit for benefits of all kinds in justifying such improvements, in governing the scope of their planning, and in selecting their priority. The value of time may well be influential in shaping the yearly programs of construction and the character of future highway systems.

The foregoing observations are not intended as criteria for determing the value of time. Rather it is hoped to provoke extended discussion which will rapidly further our knowledge of the subject. Early conclusions as to time values will enhance the planning process of highway projects now under consideration.

DEPARTMENT OF DESIGN

C. N. CONNER, *Chairman*

ACTIVITIES OF THE COMMITTEE ON REINFORCED CONCRETE RESEARCH OF THE AMERICAN IRON AND STEEL INSTITUTE

C. A. WILLSON, *Research Engineer, American Iron and Steel Institute*

SYNOPSIS

The Committee on Reinforced Concrete Research of the American Iron and Steel Institute has sponsored laboratory research in reinforced concrete since its organization in November 1943. This paper describes the various projects, giving objectives and conclusions wherever final results are available.

The first research project was established at the University of Illinois to study reinforced concrete wall and column footings. Tests were begun in the spring of 1944 and were finished in the spring of 1948.

Important developments from these tests include: (a) Definite proof that the the tensile and bond resistance depend upon the bending moment and shear found by statics by consideration of the full applied load, and not 85 percent thereof, as assumed in current building codes; (b) Hooked ends of bars showed no particular advantage in bond resistance over straight bars, particularly when deformed bars of new improved types were used; (c) Hooked bars produced very little effect on resistance to diagonal tension, much less than is commonly assumed; (d) Welded mats proved particularly effective in resisting end slip of bars; (e) Footing caps or piers are effective in reducing the amount of reinforcement and in increasing the load capacity of footings; and (f) Diagonal tension seems to be the point of weakness in current design practice. The factor of safety of thin footings in this respect appears greater than in thick footings, and is generally greater in rectangular than in square footings when the conventional methods of computation are used.

Two investigations of the comparative bonding efficiencies of more than twenty different designs of reinforcing bars have been conducted at the National Bureau of Standards. Three sizes of bar have been tested in both beam and pull-out specimens with three strengths of concrete. Bars were placed in both bottom and top position and slip values were measured at both loaded and free ends. The data have not yet been assembled but a report should be available in published form in the near future.

In October 1946 we established a research project at Cornell University to study the longitudinal distribution of bond stress in reinforced concrete members. A new and unusual technique has been employed in which the reinforcing bar is split lengthwise, a small groove is cut on the interior of the bar to permit the placement of SR4 strain gages and their connections on the inside.

In general, the conclusions to be drawn from the results obtained thus far are

as follows: Cracks affect bond stress distribution and magnitude decisively. The bond stresses near cracks in beams are high. The usual assumption that the value of the bond stress is proportional to the shear is not borne out by these tests. Cracks in beams with deformed bars were reasonably well distributed while in beams with plain bars the cracks were localized over a relatively short length of bar.

Plain bars without hooks both in pull-out tests and in beams failed in bond by excessive slips of the bars at loads between $\frac{1}{3}$ and $\frac{2}{3}$ the yield strength of the bars. The use of hooks on plain bars seemed to make them almost as effective in ultimate capacity as deformed bars but these plain bars "hang from the hook" while the deformed hooked bars develop considerable bond along their straight length. Deformed bars of the type used in this series develop bond strength high enough to produce fractures of the bars in all specimens rather than bond failure.

Three new projects started in 1948 are as follows: At the National Bureau of Standards, in a series of tests on shear or diagonal tension in beams, we are measuring the actual stresses in conventional vertical stirrups by means of SR4 strain gages.

At Iowa State College two small research projects have been established dealing with the spacing of bars in joists and beams and the other relating to lapped splices.

At the University of Wisconsin we are studying the long-time plastic flow of long span, shallow slabs and beams using tensile steel only in certain members and both tensile and compressive steel in others. As a result of this investigation we expect to learn how to reduce plastic flow by means of compressive steel.

The members of the Committee on Reinforced Concrete Research of American Iron and Steel Institute have been selected from the 19 companies that produce concrete reinforcing bars,—both billet steel and rail steel. The Committee was organized in November, 1943 and my predecessor, the late Roy Zipprodt, was employed as Research Engineer to take charge of its activities. During 1944 and 1945 he held conferences with engineers in 15 of the major cities of the United States for the purpose of securing ideas as to the problems in reinforced concrete design and construction which needed study. A total of over 400 men attended these meetings and many suggestions were obtained. Necessarily certain problems were mentioned repeatedly and thus Mr. Zipprodt was able to determine those matters in which there was greatest interest.

A review of this material led naturally to the establishment of worthwhile research projects conducted under men of recognized standing at several leading educational institutions and at the National Bureau of Standards.

The first research project was established at the University of Illinois under the direction of Professor Frank E. Richart to study reinforced concrete wall and column footings. Tests were begun in the spring of 1944 and were finished in the spring of 1948. The investigation was divided into seven groups or series; one on wall footings and the rest on column footings. The wall footings were 5 ft. wide, 2 ft. long and carried a wall section 12 in. wide. Twelve rectangular footings were studied, half of them being 6 ft. by 9 ft. and half of them 5 ft. by 10 ft. All of the other footings were 7 ft. square with a column stub 14 in. square. The three major series of tests were designed so as to fail primarily by diagonal tension, bond or tension in the steel. Those three series constituted the major part of the investigation. A few tests were made with welded bar mats and a few tests were made on footings with a cap or pier 21 in. square situated between the column stub and the footing slab.

For the most part, concrete having a 28-day compressive strength of 3,000 to 3,500 psi. was used. However, a few tests were made with concretes having strengths of 2,000 and 4,000 psi. Several kinds of reinforcing steel were used including plain rail, old and new deformed rail, and old and new deformed billet.

Important developments from these tests include the following:

1. Definite proof that the tensile and bond resistance depend upon the bending moment and shear found by statics by consideration of the full applied load, and not 85 percent thereof, as assumed in current building codes;

2. Hooked ends of bars showed no particular

advantage in bond resistance over straight bars, particularly when deformed bars of new improved types were used;

3. Hooked bars produced very little effect on resistance to diagonal tension, much less than is commonly assumed;

4. Welded mats provided exceptionally good anchorage of the reinforcing steel. Such mats made with straight bars of the improved deformed type should give excellent resistance to bond failure;

5. Footing caps or piers are effective in reducing the amount of reinforcement and in increasing the load capacity of footings; and

6. Diagonal tension seems to be the point of weakness in current design practice. The factor of safety of thin footings in this respect appears greater than in thick footings, and is generally greater in rectangular than in square footings when the conventional methods of computation are used.

Professor Richart has prepared an excellent report on this project which has just been published in the October and November issues of the *Journal* of the American Concrete Institute. The results of these tests should provide the Building Code Committee of the American Concrete Institute with ample justification for the elimination of the present requirement that all bars in footings must be hooked.

The second research project was established at the National Bureau of Standards in Washington in August of 1944 under the direction of Mr. Arthur P. Clark to compare the bonding efficiency of 17 different designs of deformed concrete reinforcing bars. The tests were of the pull-out type in which the bars were placed horizontally in both top and bottom positions. Various lengths of embedment were used and the slip of the bar was measured at both loaded and free ends. It was established that certain bars were definitely superior in the sense that their average rating was significantly higher than the average of the others. Bars cast in the top position were much less effective than those cast in the bottom position. Mr. Clark's report on this program was published in the December 1946 issue of the *Journal* of the American Concrete Institute.

The results of this study led to the establishment of a more comprehensive series of tests at the National Bureau of Standards under Mr. Clark's direction in January of 1946. Obviously some of the bars which had not showed up too well in the earlier investigations were eliminated from further study. In this new program ten bars were included in the original schedule and a few more were added during this past year. A plain bar and a typical old-fashioned prewar deformed bar were used as bases of comparison. However, our interest centered on other patterns which were either comparatively new designs or were older designs with improvements.

All bars had a tensile strength of 85,000 psi. or better. A major part of the program was devoted to the study of ⅞-in. bars embedded in pullout specimens using concrete having a 28-day strength of 3,500 psi. Supplementing this, some tests were made using ½-in. and 1⅛-in. bars and a few tests were made with 2,000 and 6,000 psi. concretes. Bars were placed in both bottom and top positions in the specimen and slip values were measured at both loaded and free ends. A large number of beam tests were made and an excellent correlation with pull-out tests was established. Since the beam tests are much more costly and time-consuming to make, we hope that the Bond Stress Committee of the American Concrete Institute will feel justified in eliminating the necessity for their use from current test requirements. Practically all of our testing work on this program has been completed and a wealth of data has been collected. We hope to publish this information in the very near future.

Obviously the results of this investigation have a bearing on the ASTM Tentative Specifications for Minimum Requirements for the Deformations of Deformed Steel Bars for Reinforcement A305-47T which was issued last year. It seems likely that these specifications will be revised as a result of knowledge gained from these tests. This information will be utilized also by the Bond Stress and Building Code Committees of the American Concrete Institute in arriving at the amount of increase in allowable bond stress which can be allowed for the new patterns of deformed reinforcing bars.

In October 1946 we established a research project at Cornell University under the direction of Professors George Winter and Robert Mains to study the longitudinal distribution of bond stress in reinforced concrete members. A new and unusual technique has been employed in which the reinforcing bar is split lengthwise, a small groove is cut on the interior of the bar, SR4 strain gages with lead wires are placed in this groove at properly spaced intervals, and the two parts of the reinforcing bar are tackwelded together again. This eliminates the reduction of surface contact between the bar and surrounding concrete which normally takes place when such gages are attached to the outside of the bar. Obviously a good deal of time and energy was spent in machining bars, placing gages and developing new techniques. The first phase of this program using short span, deep beams has been completed while the second phase using shallower beams is progressing rapidly and should be completed early in 1949.

In general, the conclusions to be drawn from the results obtained thus far are as follows: Cracks affect bond stress distribution and magnitude decisively. The bond stresses near cracks in beams are high. The usual assumption that the value of the bond stress is proportional to the shear is not borne out by these tests. Cracks in beams with deformed bars were reasonably well distributed while in beams with plain bars the cracks were localized over a relatively short length of bar.

Plain bars without hooks both in pull-out tests and in beams failed in bond by excessive slips of the bars at loads between $\frac{1}{3}$ and $\frac{2}{3}$, the yield strength of the bars. The use of hooks on plain bars seemed to make them almost as effective in ultimate capacity as deformed bars but these plain bars "hang from the hook" while the deformed hooked bars develop considerable bond along their straight length. The straight deformed bars as well as the hooked deformed bars, develop bond strength high enough to produce fractures of the bars in all specimens rather than bond failure.

Some new projects were started in May 1948. The first one is a series of tests on shear or diagonal tension which is being conducted at the National Bureau of Standards under the direction of Mr. Clark. The object is the determination of the actual stress in conventional type stirrups. So far as we know this is the first time that SR4 strain gages have been used for the measurement of stresses of this kind and therefore quite a little work of a preliminary nature had to be done to develop techniques. This project has been carried along concurrently with that of the larger bond stress program by the same staff of men. Progress, therefore, has been slow but we believe that a great deal of valuable information will be obtained.

At Iowa State College two small research projects have been established under the direction of Professors H. J. Gilkey and S. J. Chamberlin, one relating to the spacing of bars in joists and beams and the other relating to lapped splices. In both cases we are using one of the improved types of deformed bars. Very little experimental work has been done on these two subjects and a certain amount of small scale preliminary tests had to be made before the larger scale investigations were started. In many cases in the design of reinforced concrete members for both cast-in-place and pre-cast construction there has been a tendency to disregard the rules dealing with spacing and splicing laid down by the Building Code Committee of the American Concrete Institute and other similar organizations. In our opinion, these investigations will lead to a better understanding of the actual problems involved and may lead to a revision of present day requirements.

At the University of Wisconsin a research project has been set up to study plastic flow of reinforced concrete slabs and beams. The program is in many ways a supplement to and an extension of certain pioneering studies made by Professor George W. Washa and reported in the *Journal* of the American Concrete Institute for November 1947. Those earlier studies related to very shallow long span slabs with tensile reinforcement only. Our project, which is also being conducted under the direction of Professor Washa, includes two thicknesses of slabs, two sizes of beams and many of the specimens have compressive reinforcement as well as tensile. As a result of this investigation we may find that it will be possible to reduce the deformation resulting from the plastic flow of concrete by the addition of a moderate amount of compressive steel.

We believe that the Committee on Reinforced Concrete Research of the American Iron and Steel Institute is engaged in a well-balanced program of research. As rapidly as these projects are completed, reports will be prepared and published. Suggestions as to additional problems needing study will be gratefully received.