# REPORT OF COMMITTEE ON THE USE OF HIGH ELASTIC STEEL AS REINFORCEMENT FOR CONCRETE

H. J. GILKEY, *Chairman*

## FOREWORD

This report constitutes Chapter XI of a continuing project made up of a series of investigations of problems relating to the use of high elastic limit steel as reinforcement for concrete.

The titles and authorship of the past and current chapters are as follows:

- Chapter I. Questions and Their Status. Vol. 14 (1934), p. 258-270. (Gilkey and Ernst.)
- Chapter II. References and Brief Summaries. Vol. 14 (1934), p. 271-283. (Gilkey and Ernst.)
- Chapter III. Design Procedure and Possible Economies from the Use of Higher Design Stresses. Vol. 14 (1934), p. 283-314. (Gilkey and Ernst.)
- Chapter IV. Sustained Loading Tests on Slender Concrete Beams Reinforced with High Elastic Limit Steel. Vol. 15 (1935), p. 81-111. (Gilkey and Ernst.)
- Chapter V. Pullout Tests for Bond Resistance of High Elastic Limit Steel Bars. (Reconnaissance Series of 1936) Vol. 16 (1936), p. 81-95. (Gilkey and Ernst.)
- Chapter VI. An Experimental Study of Bond Stress. Vol. 16 (1936), p. 96-99. (Dunagan and Ernst.)
- Chapter VII. Concrete Slabs Reinforced with High Yield Point Steel Bars. Vol. 16 (1936), p. 100-114. (Mylrea.)
- Chapter VIII. Bond Resistance of High Elastic Limit Steel Bars; Series of 1937. Vol. 17 (1937) p. 150-186. (Gilkey, Chamberlin and Beal. )
- Chapter IX. The Distribution of Strain in the Concrete of Pullout Specimens; Series of 1937, Vol. 18 (1938) p. 114-129. (Gilkey, Chamberlin and Beal.)
- Chapter X. The Effects of Impact on Reinforced Concrete Beams. Vol. 18 (1938) p. 130-139. (Mylrea.)
- Chapter XI. Bond Tests on Rusted Bars. Vol. 19 (1939) p. 149 (Gilkey, Chamberlin, and Beal.)

The work reported as Chapter XI was conducted at Iowa State College as a cooperative project between the Highway Research Board and the Iowa Engineering Experiment Station.

The results were submitted to the members of the project committee and are recommended by them to the Department of Design for publication. The project committee as now constituted consists of:

- G. C. Ernst, Assistant Professor of Civil Engineering, University of Maryland.
- T. D. Mylrea, Professor and Head of Civil Engineering, University of Delaware.
- F. E. Richart, Research Professor of Theoretical and Applied Mechanics, University of Illinois.
- Searcy B. Slack, Consulting Engineer, Decatur, Georgia.
- H. J. Gilkey, Professor and Head of Theoretical and Applied Mechanics, Iowa State College, Chairman.

In November 1939 the committee lost by death A. L. Gemeny, Senior Engineer, Public Roads Administration who had been a valued member of the committee since its formation in 1933

# CHAPTER XI. BOND TESTS ON RUSTED BARS


By H. J. Gilkey, *Professor and Head*
S. J. Chamberlin, *Assistant Professor*, and R. W. Beal, *Instructor*
*Department of Theoretical and Applied Mechanics, Iowa State College*



## SYNOPSIS

Plain round $\frac{5}{8}$-in. rail steel bars were exposed to the weather for 0, 1, 2, 3, 4, 6, 7, and 8 months respectively. Rust formation was observed and measured by abrading the rust and weighing it. On companion bars the rust was: (a) left unmolested, and (b) wiped off with burlap. All bars were vertically cast into 4 by 4 by 10-in. 28-day pullout specimens ($L/D = 16$) and observations were taken for "first slip," ultimate bond resistance and drag resistance after a slippage of 0.08 in. Amounts of slippage were measured at both the loaded and the unloaded ends of the bars. The general conclusions reached are that the light layer of loose powdery red rust that first forms is of negligible importance and that firm rust tends to increase bond resistance. After the rust became deep, loose and flaky, as for the longest exposures, bond was reduced moderately but wiping the loose rust off with burlap more than restored the bond to that of the unrusted bar. Tests and measurements show that even for the longest exposures which gave deep loose layers of rust there was no significant reduction in bar cross-section because of the rust. The volume of rust is much greater than that of the steel from which it was formed. The results secured are in essential agreement with the limited recorded findings of the other investigators listed as references.


For most climates and most job conditions, it is practically impossible to prevent some rusting of reinforcement prior to its use in concrete. The extent to which rust on bars may effect the bond resistance that they can develop has long been a moot question.

Generally speaking, the practice has been to tolerate a limited amount of firm rust, but the element of personal judgment involved in distinguishing between firm and loose rust and in deciding when the rust was excessive has in itself occasionally been a source of bickering between the materials dealer and the contractor or between the contractor and the inspector or engineer. Even if the classification and measurement of rust were easily accomplished, the fact remains that very little is known about the influence of any specific kind or degree of rust on potential bond resistance.

Such reconnaissance data as have been available (appended references No. 1 to 5) have been reassuring but at best the data are meager.

Accurate quantitative or qualitative measures of rust are important only to the extent that the amount of the rust or its nature is found to have a significant bearing upon the usefulness of the bar, either through its influence upon the effective area of cross-section or through its effect upon the bar surface and the bond that can be developed.

### OUTLINE OF THE PROBLEM

Perhaps a series of questions will best set forth some of the interrelated aspects of the general problem.

1. How does each of the following types of rust on bars influence the bond that they can develop as reinforcement: (a) Early-stage rust; a shallow, loose coating that rubs off easily; powdery when dry? (b) Intermediate-stage rust; a firm fairly deep-seated more or less continuous cover only the surface of which can be removed easily by ordinary rubbing? (c) Late-stage rust; thick multiple layers, the outside portions being loose, flaky and easily detached?

2. Such terms as loose and firm; shallow and deep, as applied to rust are indefinite

and are subject to variable interpretations. Is it practicable to devise methods for measuring relative amounts of rust by scraping off and weighing, by successive direct measurements of bar diameters, or by studying the thickness of the rust layers photomicrographically, or otherwise, and to correlate the measured amounts of rust with the bond resistance that can be developed by the bars?

3. Is the progress made by rust formation proportional to the period of exposure in a given environment?

4. For bars of a given diameter, at what stage do the inroads of the rust upon the effective area of cross-section of the bar become significant in reducing its load-carrying capacity?

5. Limited, previous reconnaissances have indicated that firm rust is beneficial rather than detrimental to bond. It seems probable, however, that rust which has reached the stage of multiple layers of loose flaky material must inevitably lower potential bond development. What reasonable measures may there be, if any, to restore at small cost, an over-rusted surface to a condition at least as satisfactory as the norm (the unrusted bar)?

## OUTLINE OF THE TESTS

Question 1 called for a graduated series of tests by which rust could be observed and studied in its various states and stages. Preliminary studies showed that the rust itself is not one simple oxide of iron, but that on the same bar there may be present rusts of several different compositions.

For the purpose of this paper rust is considered to be any of the various types of coating that may form on the bar as the result of exposure to moisture. Oxide coatings on some metals are protective in nature in that they form a surface film that prevents penetration of the corrosive influence as long as the film remains intact. Rust is not of this class, since the conditions beneath a layer of rust are favorable to continued rust formation and penetration as long as moisture continues to be available. Once fully embedded in sound concrete rust formation ceases under even rather severe exposure and the problem here considered relates only, therefore, to the rusting of exposed, unembedded bars.

Consideration was given to the desirability of attempting to produce rust rapidly by using salt water or other chemical corrosives, and some preliminary experiments were conducted with this possible procedure in mind, but it was decided that outdoor exposure was preferable, providing the time required to produce measurable different degrees of rust didn't prove to be too great. For one thing, there was the probability that there would be present residually enough of the corrosive agent to react with the cement and thereby complicate the results from the bond tests.

The steel consisted of nine ⅝-in. diameter plain round rail-steel bars each 10 ft. long. These were part of the same lot of material which was used for the bond tests reported in Chapters VIII and IX (Vol. 17 and 18, *Proceedings* Highway Research Board). Relatively small bars were selected, partially to keep the maximum pull developed by pullout specimens within the capacity of the 20,000 lb. testing machine best adapted for the work, and partially to exaggerate the rust effects because of the greater specific surface of small bars. Plain bars were selected because it was believed that characteristic rust effects could better be identified if the complicating effects of lug action were excluded for the present. Reference No. 5 reports briefly and in part some results from contemporary tests of rust effect on the bond developed by deformed bars.

Figure 1 shows how each bar was sub-

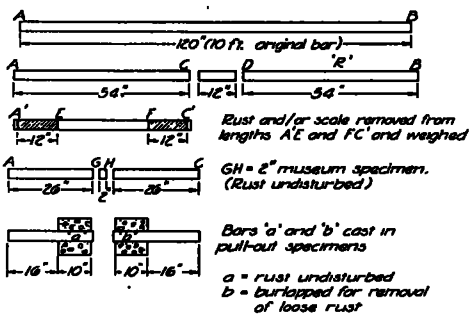



**Figure 1. Allocation of Original 10 ft. Length of Bar. Portion marked "R" (DB length) is reserved for possible follow-up tests.**

divided and the treatment accorded to each portion. Lengths CD were reserved as unrusted strength controls for the comparative tensile tests reported in Table 1. The relatively short 10-in. embedments (L/D = 16) used for the pull-out specimens insured slippage at tensile stresses which were well below the yield point of this steel, as may be noted by comparing the yield points of Table 1 (Col. h) the lowest of which was at a total load of 15,500 lb. (about 50,500 lb. per sq. in.) with the maximum load developed in a pullout test (Table 2 Col. e)

TABLE 1.

COMPARATIVE MEASUREMENTS OF DIAMETERS AND STRENGTHS OF BARS AS CHECKS ON POSSIBLE REDUCTION OF SECTIONS BY RUST

| Spec. No. | Length (Fig. 1) | Exposure | Mean diam. (in.) | Max. deviation (spread) (in.) | Av. deviation in diam. (in.) | Apparent reduction in area % | Total load (lb.) | | Apparent strength reduction due to rust % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Y. P. | Ult. | Y. P. | Ult. |
| a | b | c | d | e | f | g | h | i | j | k |
| 0 Str. Control.. | CD | None | 0.627 | 0.008 | .003 | ... | 19,825 | 32,825 | Not | rusted |
| 0 Rust Control. | AG(a)[1] | None | .624 | .008 | .003 | ... | 19,700 | 32,875 | Not | rusted |
| 0 Rust Control. | HC(b)[1] | None | .625 | .009 | .002 | ... | 19,925 | 32,775 | Not | rusted |
| 1 Str. Control.. | CD | None | 0 627 | 0.008 | .003 | ... | 19,825 | 32,825 | Not | rusted |
| 1 Rusted...... | AG(a) | 1 Mo. | .624 | .010 | .003 | 1.0 | 19,800 | 32,600 | 0.1 | 0.7 |
| 1 Rusted...... | HC(b) | 1 Mo. | .625 | .009 | .003 | 0.6 | 19,675 | 32,650 | 0.8 | 0.6 |
| 2 Str. Control.. | CD | None | 0 627 | 0.007 | .002 | ... | 16,520 | 31,250 | Not | rusted |
| 2 Rusted...... | AG(a) | 2 Mo. | .626 | .009 | .003 | 0.3 | 16,225 | 31,125 | 1.8 | 0.4 |
| 2 Rusted...... | HC(b) | 2 Mo. | .627 | .007 | .002 | 0.0 | 16,425 | 31,275 | 0.6 | 0.1[2] |
| 3 Str. Control.. | CD | None | 0.626 | 0.008 | .002 | ... | 16,600 | 31,200 | Not | rusted |
| 3 Rusted...... | AG(a) | 3 Mo. | .625 | .007 | .002 | 0.3 | 16,420 | 31,175 | 1.2 | 0.1 |
| 3 Rusted...... | HC(b) | 3 Mo. | .624 | .008 | .002 | 0 6 | 16,325. | 30,975 | 1.7 | 0.7 |
| 4 Str. Control.. | CD | None | 0.629 | 0.008 | .002 | ... | 19,650 | 32,300 | Not | rusted |
| 4 Rusted...... | AG(a) | 4 Mo. | .627 | .006 | .002 | 0.6 | 19,150 | 32,225 | 2.5 | 0.2 |
| 4 Rusted..... | HC(b) | 4 Mo. | .626 | .004 | .002 | 1.0 | 19,450 | 32,275 | 1 0 | 0.1 |
| 6 Str. Control . | CD | None | 0.628 | 0.004 | .001 | ... | 18,450 | 30,125 | Not | rusted |
| 6 Rusted...... | AG(a) | 6 Mo. | .626 | .006 | .002 | 0.6 | 18,300 | 30,175 | 0 8 | 0 2[2] |
| 6 Rusted...... | HC(b) | 6 Mo. | .625 | .005 | .001 | 1.0 | 18,320 | 30,175 | 0.7 | 0 2[2] |
| 7 Str. Control.. | CD | None | 0.630 | 0.010 | .003 | ... | 15,550 | 25,900 | Not | rusted |
| 7 Rusted...... | AG(a) | 7 Mo. | .626 | .007 | .002 | 1.3 | 15,725 | 25,675 | 1.1 | 0.9 |
| 7 Rusted...... | HC(b) | 7 Mo. | .626 | .006 | .001 | 1 3 | 15,500 | 25,725 | 0.3 | 0.7 |
| 8 Str. Control . | CD | None | 0.628 | 0.005 | .001 | ... | 18,450 | 30,300 | Not | rusted |
| 8 Rusted...... | AG(a) | 8 Mo. | .625 | .005 | .001 | 1.0 | 18,375 | 30,175 | 0.4 | 0.4 |
| 8 Rusted...... | HC(b) | 8 Mo. | .626 | .008 | .003 | 0.6 | 18,350 | 30,125 | 0.5 | 0 6 |

NOTES: Cols. d, e, and f are from 10 micrometer measurements at approximately one-inch intervals along each bar; adjacent diameters at right angles. [1]Rust Controls No. 0 were from the DB length of Bar No. 1. (See Fig. 1). Strength Controls No. 0 and No. 1 are identical, being CD length of Bar No. 1. [2]Increase.

12,920 lb. (about 42,200 lb. per sq. in.). Most of the yield points were above 60,000 lb. per sq. in. and most of the maximum tensile stresses developed by No. 1 which was numbered 0 and used for a pair of unexposed rust controls. The eight AC lengths were exposed, starting July 26, 1938, on an outside west-

TABLE 2

Data From the Pullout Tests

| Days exposed | Spec. No. | Rust[1] (grams) | Load on bar (lb., above) (lb. per sq. in., below) | | | Bond stress (p. s. i., above) (% of first slip, below) | | | Slip at ult. (in.) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | First slip | Ult. | Drag[2] | First slip | Ult. | Drag[2] | Loaded end | Free end |
| a | b | c | d | e | f | g | h | i | j | k |
| 0 | 0 | 1.004 | 9530 | 10,430 | 7080 | 474 | 519 | 352 | 0.0125 | 0.0052 |
| | | | (31,000) | (34,000) | (23,100) | | (109.5) | (74.3) | | |
| | 0 | | 10,030 | 12,330 | 8180 | 499 | 614 | 407 | 0.0192 | 0 0100 |
| | | | (32,700) | (40,200) | (26,600) | | (123.0) | (81.6) | | |
| 38 | 1-a | 1.595 | 10,400 | 12,370 | 8480 | 518 | 615 | 422 | 0 0209 | 0.0104 |
| | | | (33,900) | (40,300) | (27,600) | | (118.8) | (81.5) | | |
| | 1-b | | 9000 | 9910 | 6440 | 448 | 493 | 320 | 0.0118 | 0.0053 |
| | | | (29,300) | (32,300) | (21,000) | | (110.0) | (71.5) | | |
| 62 | 2-a | 1.676 | 11,000 | 12,920 | 9220 | 547 | 643 | 458 | 0.0198 | 0.0098 |
| | | | (35,900) | (42,200) | (30,100) | | (117.5) | (83.7) | | |
| | 2-b | | 9400 | 11,540 | 8230 | 467 | 575 | 409 | 0 0179 | 0.0101 |
| | | | (30,600) | (37,600) | (26,800) | | (123.1) | (82.5) | | |
| 92 | 3-a | 1.366 | 10,720 | 11,290 | 7340 | 534 | 561 | 365 | 0.0128 | 0.0048 |
| | | | (35,000) | (36,800) | (23,900) | | (105.0) | (68.5) | | |
| | 3-b | | 8000 | 10,450 | 8100 | 398 | 520 | 403 | 0.0181 | 0.0100 |
| | | | (26,100) | (34,100) | (26,400) | | (130.7) | (101.1) | | |
| 121 | 4-a | 1.811 | 8000 | 9480 | 6130 | 398 | 472 | 305 | 0.0170 | 0.0101 |
| | | | (26,100) | (30,900) | (20,000) | | (118.6) | (76.6) | | |
| | 4-b | | 8980 | 10,600 | 6980 | 447 | 528 | 347 | 0.0128 | 0.0052 |
| | | | (29,300) | (34,600) | (22,700) | | (118.0) | (77.6) | | |
| 184 | 6-a | 3.414 | 9570 | 10,380 | 6200 | 476 | 516 | 308 | 0.0129 | 0.0050 |
| | | | (31,200) | (33,800) | (20,200) | | (108.3) | (64.6) | | |
| | 6-b | | 9980 | 11,480 | 6750 | 496 | 571 | 336 | 0.0139 | 0.0050 |
| | | | (32,500) | (37,400) | (22,000) | | (115.0) | (67.8) | | |
| 212 | 7-a | 4.371 | 9420 | 10,980 | 6560 | 468 | 546 | 326 | 0.0175 | 0.0100 |
| | | | (30,700) | (35,800) | (21,400) | | (116.7) | (69.7) | | |
| | 7-b | | 11,230 | 12,760 | 8120 | 559 | 634 | 404 | 0.0147 | 0 0050 |
| | | | (36,700) | (41,600) | (26,500) | | (113.3) | (72.3) | | |
| 242 | 8-a | 4.597 | 8970 | 9640 | 5360 | 446 | 479 | 267 | 0.0112 | 0.0050 |
| | | | (29,300) | (31,400) | (17,500) | | (107.5) | (59.9) | | |
| | 8-b | | 10,020 | 12,520 | 7860 | 499 | 624 | 391 | 0.0202 | 0.0100 |
| | | | (32,700) | (40,800) | (25,600) | | (125.0) | (78.4) | | |

[1]Rust in grams from 24 inches of bar.
[2]Drag is taken as the load (or bond stress) after a slippage of 0.08 in.
Bar 1-a, 2-a, etc., rust undisturbed.
Bar 1-b, 2-b, etc., wiped with burlap.

bond were 40,000 lb. per sq. in. or below. No bar reached or even closely approached its yield point during the pullout test.

The 54-in. DB lengths were stored for possible future tests except that for bar exposure ledge at the third floor level of the Laboratory of Mechanics, as illustrated in Figure 2. Figure 3 shows the surface texture appearance of the bars just prior to exposure.

At intervals of approximately one

month, one bar was removed and stored indoors where the air was relatively dry and presumably no further rusting or surface change occurred. The last bar, damaged through misuse by a laboratory assistant and there is, therefore, one gap in the series.

Figure 4 is a close-up photograph of

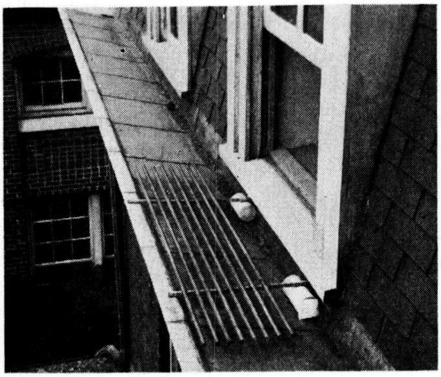


Figure 2. Exposure of Bars on West Ledge of Laboratory of Mechanics at third floor level.

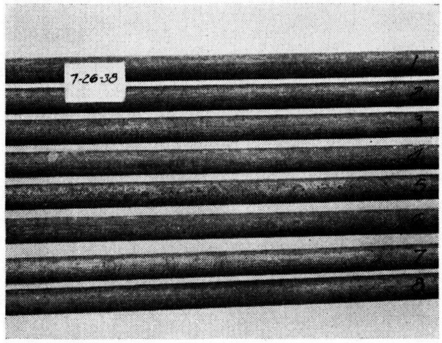



Figure 3. Bars prior to starting Exposure on July 26, 1938

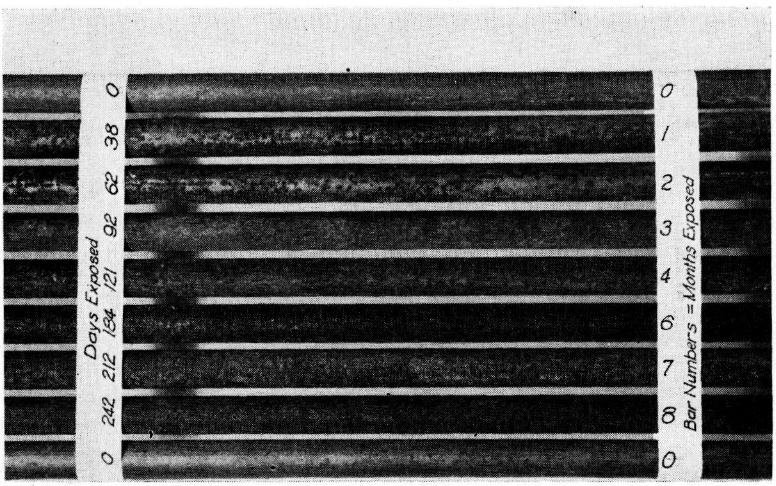



Figure 4. Bars after Exposure. Outside Bars are Unexposed Controls. Bar No. 5 Missing

No. 8, had had, at the end of the period, an outdoor storage of eight months which included the months of August 1938 to March 1939.

The rusted surface of Bar No. 5 (5 months exposure) was inadvertently

all bars (except No. 5) after exposure, the two outside bars of the photograph being the two unexposed control portions of the DB length of No. 1 which are numbered 0. The reserve supply, exclusive of the 12-in. tensile specimens,

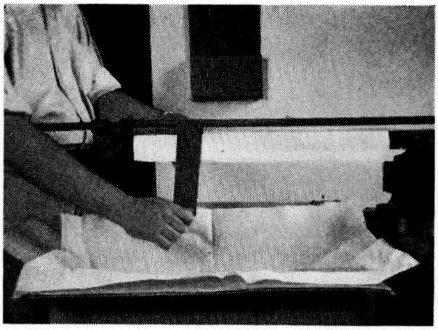


Figure 5. Emery Cloth removal of Rust for weighing. From two 12-inch lengths of each Bar.

was repeated. A new strip of emery cloth was used for each 12-in. length. The details of the process had been evolved by trial to secure rubbed surfaces virtually free of rust and scale. The amount of rust and/or scale secured from the two 12-in. lengths of bar was determined by weighing both the receiving paper and the emery cloth on a pair of analytical balances, before and after the treatment. As shown by Figure 6, a measurable amount of scale was secured from the unrusted bar. The rust secured from the other bars increased in more or less direct proportion to the period of outdoor ex-

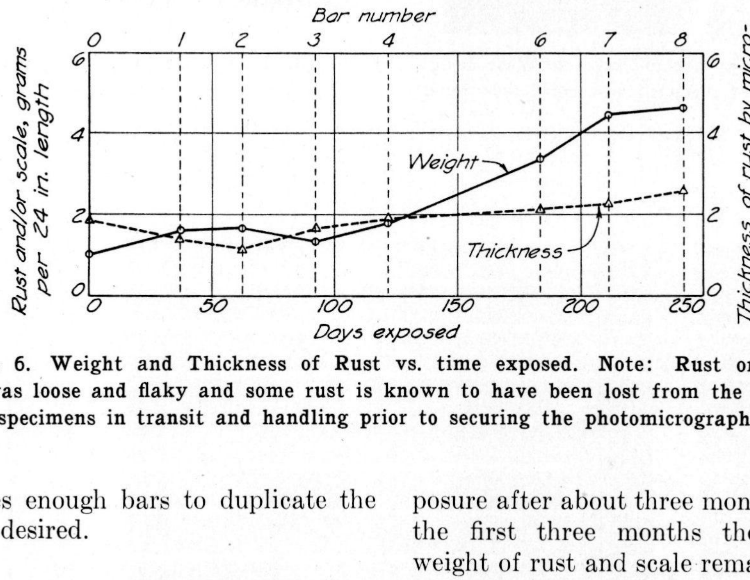



Figure 6. Weight and Thickness of Rust vs. time exposed. Note: Rust on bars 6, 7 and 8 was loose and flaky and some rust is known to have been lost from the photomicrographic specimens in transit and handling prior to securing the photomicrographs.

comprises enough bars to duplicate the series if desired.

MEASUREMENT OF AMOUNTS OF RUST

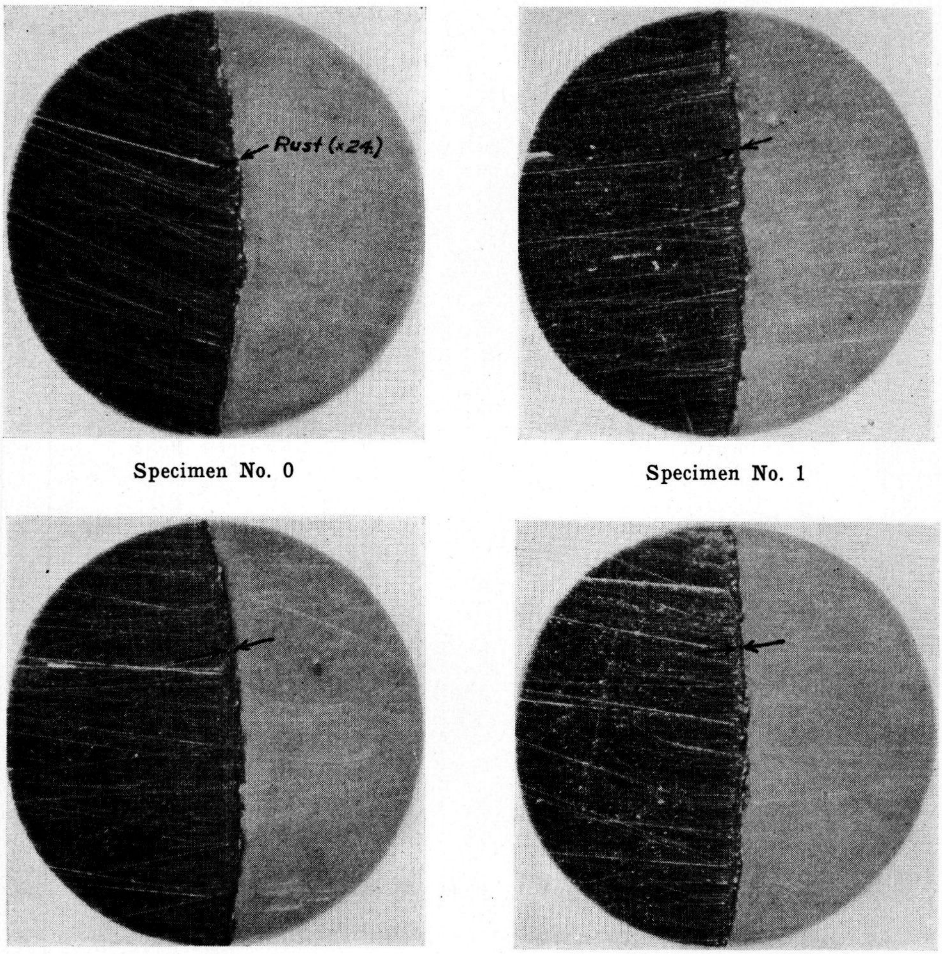
To answer Questions 2 and 3 means had to be devised for measuring or estimating amounts of rust. Two techniques were used: (a) Each 54-in. length of bar was mounted as shown in Figure 5 and two 12-in. lengths near the ends were given 100 passes with a 2 by 10 in. strip of No. 100 emery cloth, all debris (rust and/or scale) being carefully collected on a paper as indicated. The bar was then rotated $\frac{1}{3}$ of a turn and the process

posure after about three months. During the first three months the combined weight of rust and scale remained nearly constant. The authors had not expected to find such an excellent progression and easily definable rate of rust formation as these tests disclosed. (b) The 2-in. museum specimen lengths (GH of Fig. 1) were sent to Ivan Racheff, Testing and Metallurgical Engineer of Chicago, for added study and analysis. Cross-sections were photographed at 24 diameters (Figs. 7 and 8). From these were measured the approximate depth of the rust layer then present. These are plotted on

Figure 6 and show the same general trend of consistent increase with added exposure as was shown by the rust-removal tests. Had there not inevitably have been some loss of rust from the flaky surfaces of samples 6, 7 and 8, the trends of the curves would be in still better agreement.

Obviously a third method would have been to weigh equal lengths of bars before exposure and after rust removal but for the conditions of these tests it was more satisfactory to weigh the rust removed as per method (a).

The process of rust formation was noted rather carefully. Very soon after exposure the bars developed a film of loose red rust which came off readily on the hands or any other contacting surface. This rust seems to exert little or no significant influence on the bond. Evidently it is dispersed as the concrete is




Specimen No. 0

Specimen No. 1

Specimen No. 2

Specimen No. 3

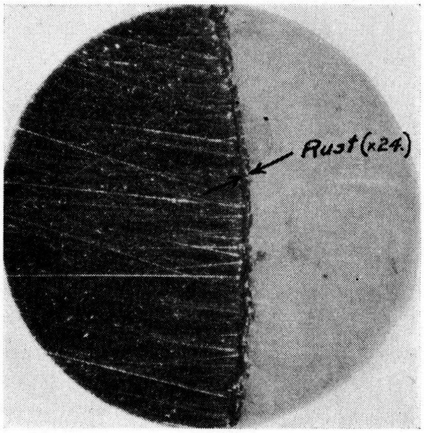
**Figure 7. Depths of Rust. Photomicrographs (× 24). Specimens No. 0, 1, 2, 3**

placed, and the thin film of first-stage rust is not germane to the problem. At one month the rust was mainly of this type.

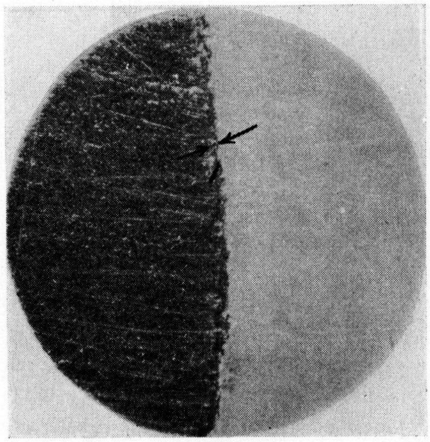
While the rust increased visibly from the beginning of the exposure as is apparent in Figure 4, the weight of combined mill scale and rust secured was about constant for all bars up to three-months exposure, as shown by the plotted weights on Figure 6. Weather may also have influenced the rate of rust formation and be responsible in part for the faster rates at the greater ages.

The layer of rust increased in thickness but remained quite firm for exposures up to 6 or 7 months, after which the outside portions began to get flaky and loose, being pushed off as the newer layers formed below.

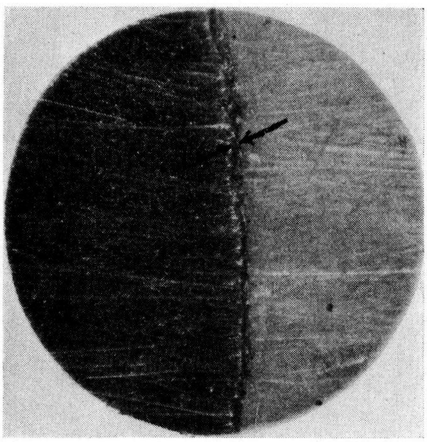
The eight-months overall exposure period proved to be excellent for securing



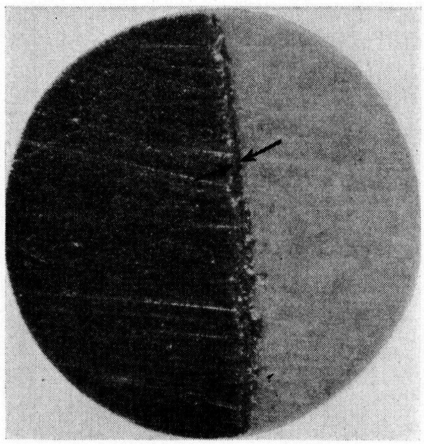

Specimen No. 4



Specimen No. 6



Specimen No. 7



Specimen No. 8

**Figure 8. Depths of Rust. Photomicrographs (× 24). Specimens No. 4, 6, 7, 8**

a good range of rust formation. The type and thickness of the rust layer at eight months had passed anything that would or should be tolerated on a job without some treatment for getting rid of the scaly loose outer layer.

#### REDUCTION IN EFFECTIVE AREA OF BAR

The amount of rust formed is not a usable indication of the amount of metal destroyed because of differences between the compositions and densities of rust and steel. A thick layer of rust is formed from a very thin layer of steel. The most direct methods for determining reductions in cross-sectional areas would have been:

(a) Careful micrometer measurements of diameters at identical sections before exposure started and again after rust had been removed.

(b) Highly refined weighings of representative lengths of bars before exposure and again after rust removal.

Unfortunately the authors were thinking initially in terms of surface textures and the tests were not so planned as to include either of the techniques indicated above. The oversight was not serious since it was still easily possible to secure good evidence on the relative importance of area reduction in these tests.

All of the bars used in pullout specimens (none of which had been overstrained or damaged as previously pointed out) were recovered from the encasing concrete after test. After the rust had been removed from 10-in. lengths of bar careful micrometer measurements were taken at one-inch intervals along the bars. Table 1 summarizes the data from these measurements. The apparent reductions in diameters and area due to rust are of the same order as the normal deviations in cross-sections along any one bar and the differences due to rust are not, therefore, significant, even for the longest exposures which had heavy layers of loose flaky rust which were objectionable beyond all question.

As an added and very conclusive check on the reduction in area or in load-carrying capacity all bars were tested in tension. The results from these tests (Table 1 Col. (h), (i), (j), (k)) lead to the same conclusion, as above, that within the scope of these tests there was no significant inroad upon the effective area of any bar. The differences in strength between different bars exceed by many times the maximum difference that could be attributed to area reduction by rust. No significant reduction because of rust is apparent even between different specimens from along the same bar.

#### SURFACE WIPING OF RUSTED BARS (BURLAPPING)

Because of the uncertainties of rust effects, there has been in the absence of evidence, much difference of opinion regarding possible safe minimum requirements relative to the use of badly rusted bars in concrete. Sometimes contractors have been required to wire-brush bars at a considerable cost and in other cases a firm wiping off with burlap has been considered sufficient.

For these limited tests it seemed best to investigate the simplest device that appeared to have a reasonable chance of adequacy.

On the "a" portions of the AG lengths (Fig. 1) the rust was left undisturbed as the bar was cast with reasonable care into a pullout specimen. The "b" portions of the HC length were firmly wiped with a piece of burlap before being cast into pullout specimens. Figure 9 shows the relative appearance of the "a" and "b" bar surfaces.

#### FABRICATION AND TESTING OF SPECIMENS

With the elimination of the 5-month exposure bars there remained to be fabricated 14 pullout specimens from rusted bars (wiped and unwiped) and two controls No. 0 (unexposed and unwiped) making sixteen 4 by 4 by 10-in. pullout specimens in all as shown along with the compressive controls in Figure 10.

The specimens were cast vertically from one machine-mixed batch of concrete of proportions 1:2.7:1.6 by weight with a water-cement ratio of 0.55 by


**Figure 9. Burlapped Bars (b) vs. those on which Rust was undisturbed (a). Burlapped Bars at right in each case.**

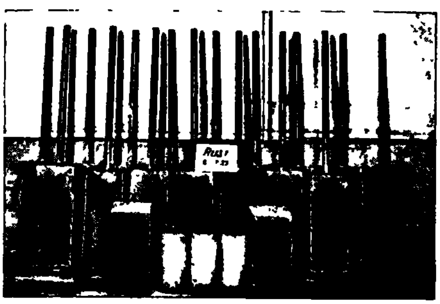


**Figure 10. Specimens: Pullouts and Compressive Controls**

weight and a slump of 6 in. Hawkeye cement and Des Moines River sand and gravel of ¾ in. maximum size were used. The mean 28-day standard-cured compressive strength of the concrete was 4430 lb. per sq. in., the prisms and cylinders giving exactly the same mean strength.

Specimens were standard-cured and tested moist at 28 days, the pullouts in a 20,000-lb. hand operated Olsen testing machine. Five Federal dials (1/10,000 in.) were arranged as shown in Figure 11 to secure data on the first slips, both at the loaded and the unloaded ends of the bar. The ultimate bond resistance and the drag resistance were also observed. First slip was taken as the load at a movement of two dial divisions (0.0002 in.) at the unloaded end and drag resistance was the load after a slippage of 0.08 in. At the loaded end slippage

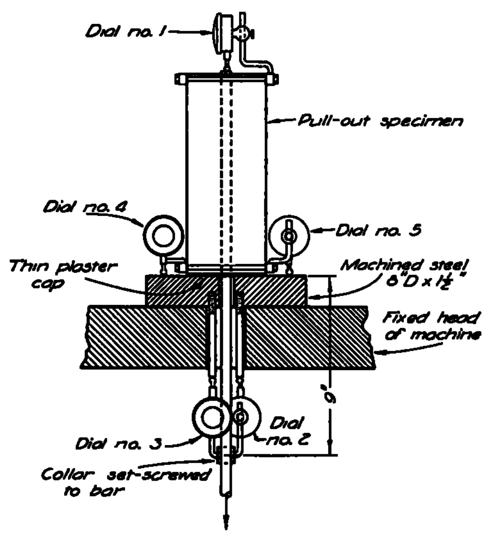



**Figure 11. Arrangement of Federal dials for measuring slippages at loaded and unloaded ends of Bar.**

started at the first increment of load which agrees with Menzel's observations (6).

### RESULTS OF PULLOUT BOND TESTS

Figures 12 and 13 show the load-slip data secured from the tests. The two specimens No. 0 were from the same bar and received identical treatments. The 10 per cent difference between the bond strengths developed is to be explained only on the basis of incidental or experimental variations.

The differences between the curves for the undisturbed and those for the burlapped bars of all the other specimens are in a graduated sequence and are, therefore, seemingly significant even though in amount they scarcely fall without the range of difference between the two identical specimens of No. 0.

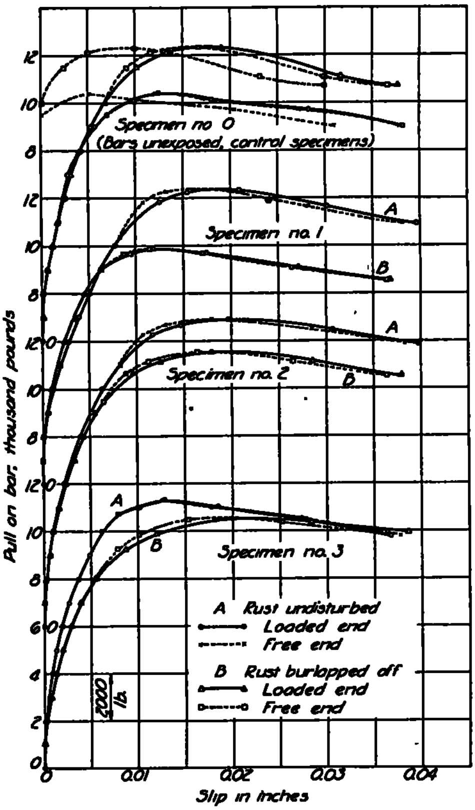



**Figure 12. Load-slip curves, specimens No. 0, 1, 2, 3**

For exposures up to three months the bars with rust undisturbed exceed in bond developed those which were burlapped but the excess decreases with period of exposure. At about three months exposure the curves cross and the burlapped bars give the higher bond strengths. At eight months the burlapped bars are nearly 20 per cent stronger in bond than are the bars with rust undisturbed.

Figures 12 and 13 show that the loaded end of the bar slipped from 0.005 to 0.008 in. before "first slip" occurred at the unloaded end. Obviously the relative movement of the two ends of a bar represents the elongation of the steel plus the shortening of the concrete within the embedded length. After slippage became general (after "first slip") the curves show that the subsequent movements at the two ends of the bar were identical, within the accuracy of measurement. This evidence indicates that there was no apparent change in the nature of the gripping after "first slip" occurred. Had there been an appreciable release or letting go, within the embedded length, the slippage differential would have de-

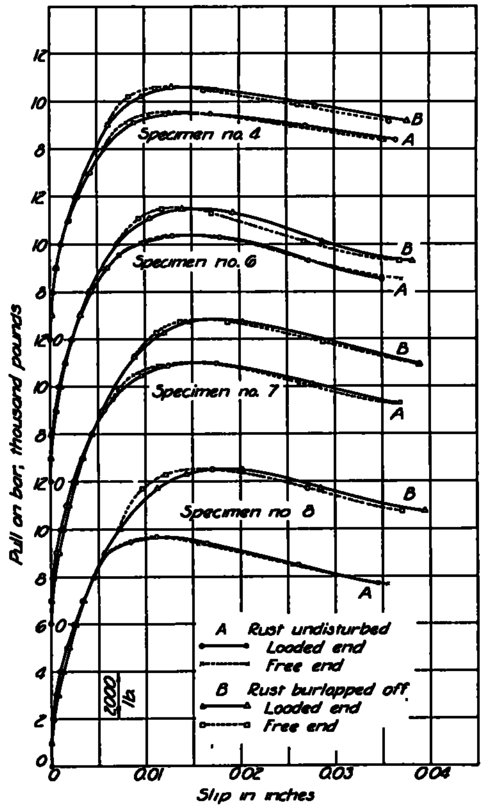



**Figure 13. Load-slip curves, specimens No. 4, 6, 7, 8**

creased and, had there been a building up of resistance, the slippage at the loaded end would have gained upon that at the unloaded end.

supply a more complete picture than has been generally available heretofore. For the top curve of Figure 12 (No. 0) the curves for slippage at the unloaded end

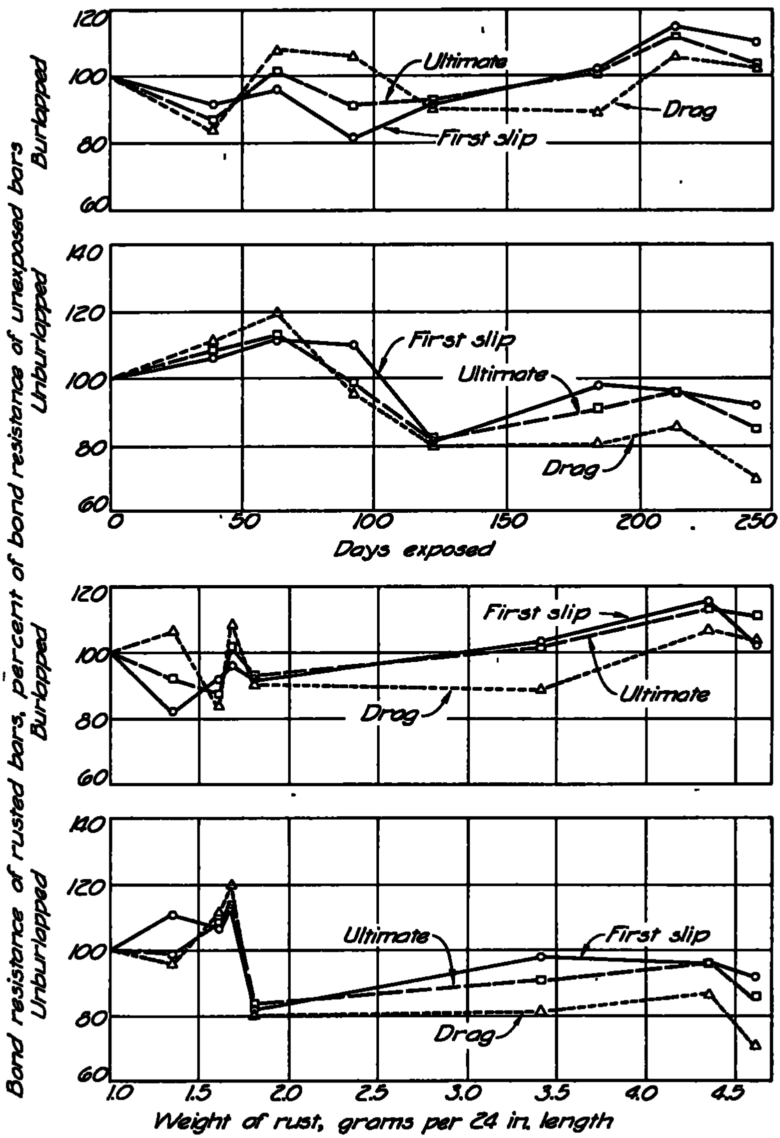



**Figure 14. Bond resistance vs. days exposed and weight of rust for both undisturbed and burlapped bars**

Previous pullout bond investigators have, with the exception of Menzel (6) secured slip data only on the bar at its unloaded end, and Figures 12 and 13 are shown twice; plotted from the axis of zero slippage as well as alongside the curves for the slippage at the loaded end.

Figure 14 shows the variation of bond

at first slip of unloaded end, at ultimate and shows drag resistance all expressed as percentages of the mean bond resistance developed by the unexposed bars. These are plotted against the number of grams of rust that were secured and also against the number of days of exposure two specimens for no exposure) the individual deviations tend to obscure possible or probable trends, but the plotted data of Figures 14 and 15 do seem to indicate rather definitely that for exposures beyond three months (90 days):

1. The bond resistance developed by

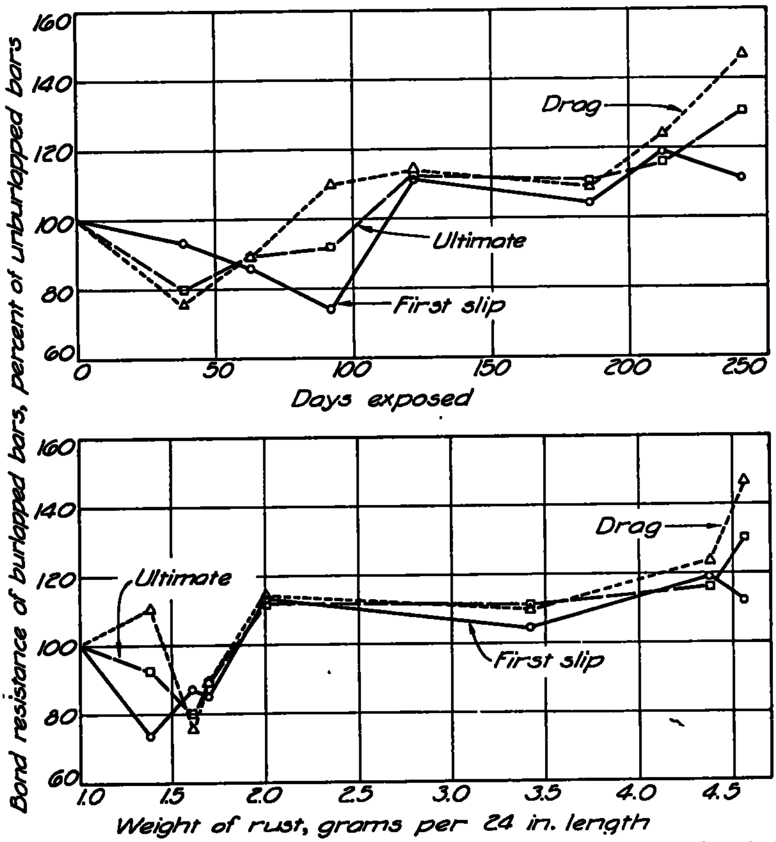



**Figure 15. Bond resistance of burlapped bars as percentage of that for undisturbed bars vs. days exposed and weight of rust**

for both the undisturbed and the burlapped bars.

Figure 15 is similar to Figure 14 except that the bond resistance developed by the burlapped bars is shown as a percentage of that developed by the bars on which the rust was undisturbed.

Because of the reconnaissance nature of the tests (there being but one pullout specimen of a kind per exposure period; the unburlapped bars (Fig. 14 second curves from top) is somewhat below that developed by the unexposed bars. There is no well defined trend, the first slip and ultimate resistance offered by the six, seven and eight-month exposure specimens all being above that of the four-month specimen, which appears to be out of line. Disregarding the four-month indication, there is a gradual and fairly well defined downward trend from about a 10 per cent increase at two months to about a 10 per cent decrease at eight months. Relative values for first slip and ultimate agree closely and drag resistance displays a similar trend.

2. For the burlapped bars (top curves of Fig. 14) the trends seem to be submerged within a plus or minus 10 per cent zone of fluctuation for exposures up to three months. From three to eight months there appears to be a rather definite upward trend seeming to indicate that simply wiping off firmly with burlap becomes increasingly effective as the bars become most deeply corroded. For even the worst corrosion (six, seven and eight months exposure) the burlapping gave surfaces which developed resistances equal to or in excess of the resistances of the unrusted bars.

3. It seems, therefore, that in spite of the undulations of the curves, the trends indicate that as the rust becomes deep and flaky, there will be some lowering of the bond resistance (restricted to about 10 per cent within the range of these tests) but that the simple inexpensive expedient of wiping the loosest of the rust off firmly with a piece of burlap can be relied upon to restore the surface to a condition where it will develop equal or greater bond resistance than it would have developed in the unrusted condition.

4. Referring now to the upper curves of Figure 15 and disregarding just now the fluctuations for exposures of less than three months, the beneficial effect of wiping off the loose layers of heavy rust is shown to be consistent and pronounced.

5. Comparing the two upper sets of curves of Figure 14 and the upper set of Figure 15 *for exposures under three months,* it seems likely that the short-time exposure effects are submerged within the range of the experimental and incidental fluctuations to be expected between individual specimens and that neither the exposures nor the burlapping exercised any significant influence upon the results secured. From Figure 14 the mean bond resistances for the burlapped and unburlapped bars slightly exceed the 100 per cent datum of the unexposed bars. By referring to Table 2 one sees that the two rust controls, the unexposed bars, differed from one another by percentages approaching the total spread or range of variation within the three-month exposure period.

From the preceding there is nothing to indicate that firm rust is detrimental to bond and in so far as the results prove anything beyond this, they tend to support the previous reconnaissances of Withey (1), Abrams (2) and the Lehigh University tests (5) that firm rust is beneficial to bond. These tests do demonstrate, moreover, that mere wiping off with burlap will more than restore the bond of the unrusted bar where the rust is deep, loose and flaky.

## CONCLUSIONS

1. For securing varying degrees of rust the outdoor exposure was satisfactory and the rust increased rather uniformly with the period of exposure in spite of wide variations in weather during the 8-month exposure period.

2. Removing the rust with the emery cloth and weighing it carefully was satisfactory as a method of rust measurement. Estimated relative areas of rust from photomicrographs of bar cross-sections gave parallel indications.

3. The differences in degrees of rust were readily visible and show up quite well in photographs.

4. The light powdery coating of red rust that appeared during the first month seems to be insignificant in its effect on bond and can safely be disregarded.

5. Within the range of experimental variation the effect of rust on bond resistance was unimportant for exposures up to three or four months. At that age the

bars had a heavy coat of firm rust and appeared much rustier than have the bars on any job within the authors' range of observation and experience.

6. For thick coatings of rust, such as those which characterized the exposures of 7 or 8 months, the bond resistance shows some reduction for the undisturbed bars, but rubbing off the loose rust with burlap produced resistances somewhat above those of the unrusted bars.

7. At all ages beyond 3 or 4 months for these tests burlapping improved the bond and it appears to be a proper and ample treatment to apply when there is question of whether or not the coating of rust is objectionably heavy or loose.

8. The indications from these tests are reassuring in that any reasonable amount of fairly firm rust on reinforcing bars is not cause for alarm. Even heavy coatings can easily be rubbed off to the point where they too need give no concern.

9. Rust is much lighter and bulkier than steel and in spite of loose thick flaky rust after seven and eight months exposure the actual reduction of cross-section was inconsequential and could scarcely be detected either by micrometer measurements or by tensile strength tests.

10. The conclusions from these tests are not out of line with those secured from a contemporary series conducted on deformed reinforcing bars at Lehigh University (5).

11. After the slippage of the bar of a pullout specimen becomes general (after "first slip," so-called) the amounts of additional slippage at the loaded and unloaded ends are equal.

## ACKNOWLEDGMENTS

The authors are indebted to the Laclede Steel Company of St. Louis for the rail steel that was used in the tests. Mr. W. A. Jennings of the Economy Form Corporation of Des Moines, supplied the steel forms which were used for casting all of the specimens except the cylinders. The authors are also indebted to Professor W. M. Dunagan and Dr. Glenn Murphy, co-workers in the Department of Theoretical and Applied Mechanics, for advice and assistance of various kinds.

The work reported herein has been conducted as one phase of a joint cooperative program between the Highway Research Board, R. W. Crum, Director, and the Iowa Engineering Experiment Station, Dean T. R. Agg, Director.

## REFERENCES

*Note:* Rather complete lists of references on bond and related researches are given in connection with chapters previously published in the Proceedings of the Highway Research Board as follows:

Vol. 14 (1934) p. 271-283, references and digests (Chapter II).
Vol. 16 (1936) p. 92-95, references and digests (Chapter V).
Vol. 17 (1937) p. 186, references, (Chapter VIII).
Vol. 18 (1938) p. 129, references, (Chapter IX).

References No. 4, 5, and 6, below, have not appeared in any of the lists of references given above.

1. M. O. Withey. "Tests on Bond between Concrete and Steel in Reinforced Concrete Beams," Bulletin 321 (1909) University of Wisconsin, (p. 46-47).
2. D. A. Abrams. "Tests of Bond between Concrete and Steel," Bulletin 71 (1913) University of Illinois Engineering Experiment Station, (p. 47-48).
3. Gilkey, Chamberlin and Beal, "The Bond between Concrete and Steel," *Proceedings* American Concrete Institute, Vol. 35 (1938-39) (Journal Sept. 1938) p. 1-20. (Rust on p. 10-11; added references on p. 19-20).
4. J. R. Shank. "Effect of Bar Surface Conditions in Reinforced Concrete," *Engineering Experiment Station News*, Ohio State University, Vol. VI, No. 3, June 1934 (p. 9-12).
5. A. E. Lindau. "Report on Rusty Bar Bond Tests and High Yield Point Steel Research," at 1939 Annual Meeting of Concrete Reinforcing Steel Institute. Preliminary report on bond tests conducted by Lyse, Johnston and Cox at Lehigh University on rusty deformed bars 1937-1939.
6. Carl A. Menzel. "Some Factors Influencing Results of Pullout Bond Tests," *Journal* American Concrete Institute, June 1939, p. 517; also *Proceedings* Vol. 35, p. 517.