# AN EXPERIMENTAL STUDY OF HOOK ANCHORAGE OF REINFORCING STEEL

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

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1949

# An Experimental Study of Hook Anchorage of Reinforcing Steel

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

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Candidates for the degree of

Bachelor of Science

June 1949

## Acknowledgements

The authors wish to express their appreciation for the help given them by Professor C. A. Miller in selecting the subject and in planning the study.

They also wish to acknowledge the courtesy and cooperation that they received from R. E. Daley, Contractor in the furnishing of the reinforcing bars used in obtaining the data for this study.

Finally they desire to express their gratitude to the Christman Company for its cooperation in furnishing the lumber used in making the concrete forms for this survey.

May 1949

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# Introduction

From almost the beginning of reinforced concrete construction anchorages for the ends of the bars have been used. The tie-rods and vertical hangers of bowstring arches, the reinforcing bars in the corners of rigid frames and bents, and the bars in beams of variable depth all furnish examples where the use of anchors is obviously necessary. It is in these cases that anchors are put to their most severe use, for it is here that they must develop the entire stress in the bars and do so without slip.

In the case of ordinary beams it was realized that the member was stronger if the bars were anchored, and the idea of increasing the safety of a structure by the use of anchors is found in the earliest works on the subject. Thaddeus Hyatt, for example, in 1876 and 1877[1] tested beams in which anchors were employed. He got his best results from beams in which flat main reinforcing bars were bent up at right angles at the ends, each end of each bar being provided with a small knob similar to a botl head. Hyatt's designs were based on a vague notion as to the interaction of steel and concrete, yet he hit suprisingly close to the design of today. The problem is not confined to the pull-out strength of an anchor, but is intimately associated with bond strength, bar strength and slip of the bar.

[1]Thaddeus Hyatt "An Account of Some Experiments with Portland Cement-Concrete Combined with Iron as a Building Material with reference to Economy of Metal in Construction and for Security against Fire in the making of Roofs, Floors, and Walking Surfaces." London 1877.

While the factors of tension, compression, and shear have been reduced to a fairly satisfactory approximate basis for purposes of design, bond, and anchorage are factors which will bear much study. Important as it is, many designs may still be found in which bond seems to have been wholly neglected. It was suspected by W.F. Scott[1] as early as 1907 that the bond in beams is not distributed in the manner indicated by the usual bond formula, and the experiments of Bach[2] and Abrams[3] fully demonstrated that such was the case. It was found that unanchored bars slipped, that when anchors were used these anchors were subject to stress, and that such anchors tended not only to prevent bond failure, but secondary failures resulting from slip.

The question of anchorage in beams falls into two parts, first, how much stress is carried by the anchor and second what constitutes an effective anchor? The first part of the question has been given various answers. Because of limited time it is not the purpose of this paper to enter into a discussion of this phase of the subject beyond making the following two statements. With steel of high elastic limit it is possible for the stress at the anchor to be almost as high as at midspan before passing the elastic limit, and with the use of higher working stresses more and more dependance must be placed upon anchorage.Secondly it is not much more difficult to devise an anchor capable of carrying a high stress than one carrying a low stress.

[1] Transactions, A.S.C.E. Vol. LXXIII, 1910

[2] Deutcher Ausschus fur Eisonbeton Hefts 9 and 10, 1911

[3] University of Illinois Bulletin 71, 1913

# THEORY

When a steel reinforcing bar is embeded in concrete, the concrete will adhere to the surface of the bar causing a resistance to any force that attempts to pull or push the bar out of the concrete. Such an adhesive force between the concrete and the steel is called the bond and the intensity of this force is called the bond stress. Therefore, it can be said that bond stress is the resistance to shearing between the steel and concrete surfaces in a direction parallel to the surface of the steel.[1] Consequently, if an axial load is applied to the free end of such an embeded steel bar and as a result of this the bar undergoes a change in length, there must be a certain amount of bond stress present in order to cause such a change.

One of the differences between bond and anchorage is that the designer does not have control of the variation of the bond stresses, for they vary with the bending moment diagram. It does not help to use a longer bar. He can obtain lower bond values by using smaller bars or by fulfilling the requirements for special anchorage (A. C. I., Art. 903). A 1-in. square bar has an area of 1 sq. in. and a perimeter of 4-in.

[1] Clarence W. Dunham, Theory and Practice of Reinforced Concrete, New York and London, McGraw-Hill Book Company, Inc., 1939, pp. 77-80.

Four 1/2-in. square bars have an area of 1 sq. in. and a total perimeter $\Sigma O = 8$ in. using four 1/2-in. square bars instead of one 1-in. square gives the same area and weight of steel but reduces the bond stresses by half, since the perimeter is doubled.

It should be emphasized that tension steel is only checked for bond while in active tension. After the positive steel passes beyond the point of inflection it is no longer in tension and the distance it then runs is regarded as anchorage. Theoretically the stress in the bar at the point of inflection is zero and its use as tension steel is completed, but it is counted for bond at this point and it is customary to run the bars farther to permit such use. In fact some of this steel is continued on the bottom into the support to give a more rigid column-beam connection and to support stirrups. Any of this steel which continues on the top towards the center is being anchored.

Anchorage does not begin for tension steel until it has passed out of the region of tension. The length of anchorage, and, hence the stress variation, are entirely at the control of the designer.

Occasionally it is not practical or possible to embed straight steel reinforcing bars far enough in concrete for them to sufficiently develop their strength by bond alone. A common method used in remedying this difficulty is to hook the ends of the bars. Such a hook provides for increased bond and shearing stresses. This hook is a standard hook as described in the 1940 J. C. C. Report (Art. 828) which specifies that it be a bar bent in a full semicircle, with a radius of bend not less than three bar diameters, plus and extension of at least four bar diameters, plus an extension of at least four bar diameters at the free end. The same specification does not consider abrupt bends, which do not engage a structural steel member, as end anchorage unless the radius of the bend is at least four bar diameters and the total length from the beginning of the bend to the free end of the bar is at least sixteen bar diameters.

The reason that such specifications should be adhered to in placing hooks in the ends of such bars may readily be explained. Figure I is a sharp right angular hook. When a load is applied to the bar possessing such a hook,

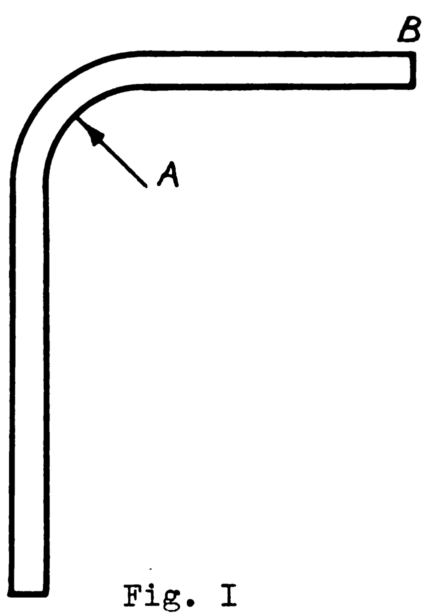



Fig. I

thus pulling it downward, the bent portion of the bar causes a compressive stress to be set up in the concrete. Since the arm AB does not have a sufficient amount of strength as a cantilever to cause the load to be spread over its entire length, it tends to crush the concrete locally at A. Also, such a downward pull on the bar is unable to produce a horizontal motion of the portion AB. Therefore, there will not be any bond developed until the bar begins to pull out below A and until it crushes a fillet in the concrete. Consequently, such a hook should be made with a fairly large radius of bend so that there will be a sufficient amount of concrete inside the bent portion of the bar in order to withstand the compression that is caused by the tension in the steel. It is also desirable that a straight portion beyond the end of the bend of the hook be provided to serve as additional anchorage.

Since no reason has been given for limiting the use of hooks to such a standard hook, other than that right-angle hooks have a tendency to cause the concrete to crush and split because of excessive bearing, we planned to perform our investigation by varying the bends in the hooks, embeding them in concrete and then exerting a tensile force on the bars until there occurred one of the three following failures:

(1) Straightening of the hook

(2) Crushing of the concrete

(3) Breaking of the bar, leaving the bar intact

Due to a limit of time and materials, it was not possible to make more test specimens. If there had not been any such limiting factors, a larger variety of bar sizes could have been used resulting in a much more complete set of data.

In determining the proper length that the steel should be embeded in the concrete specimens the following expression was used:

$$L = f_s D/4u$$

This expression was derived by considering that L, which is the length of embedment of a steel bar, must be such that the resistance to pulling out, developed with the allowable bond stress, equals or exceeds the total stress F in the bar at the face of the specimen. Therefore, letting u equal the allowable bond stress, $\Sigma o$ the perimeter of the bar, D the side of the square bar, as square bars were used in this investigation, and $f_s$ the unit tension in steel, we obtain

$$u \cdot \Sigma o \cdot L = F$$

Since $\Sigma o = 4D$ and $F = f_s \cdot A = f_s \cdot D^2$

$$u \cdot 4D \cdot L = f_s \cdot D^2$$

Giving: $L = f_s \cdot D/4u$

It might be worthwhile to note here that the same expression could also be used in determining the length of embedment of a round bar. This can readily be shown by using D as the diameter of the bar in this case. Therefore,

Since $\Sigma o = \pi D$ and $F = f_s \cdot \pi D^2/4$

$$u \cdot D \cdot L = f_s \cdot D^2/4$$

Giving: $L = f_s \pi D/4u$

As recommended by the 1940 J. C. C. Report (Art. 828), the standard hook, as well as the other types used in this survey, was considered to develop a unit stress of 10,000 psi in the bar at normal bond stress in determining the length of embedment of the steel by the above expression. This length would correspond to dimension A in Figure II.

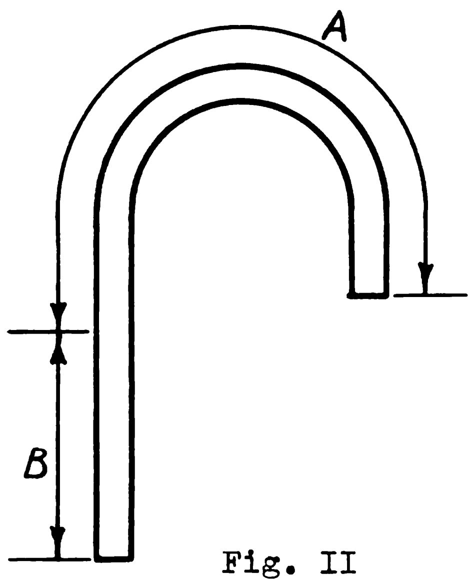



Fig. II

Dimension B was then determined by also considering a unit stress of 10,000 psi in the bar but at increased bond stress instead of at normal bond stress. Both the normal and increased bond stresses used were the recommended allowable working stresses as given in the 1940 J. C. C. Report (Art. 878).

# INVESTIGATION

Figure III illustrates the four types of hooks that were used in this survey. Since we were limited to 8-1/2" round, deformed bars and 8-3/8" round, deformed bars, each one of the four types of hooks was put in the end of two bars of both sizes. We also made two different strength concretes for each set of eight bars so that a total of four mixes were made. The two different concretes were designed for 3000 psi and 4000 psi. Two standard 6" x 12" compression test cylinders were made for each mix resulting in a total of twenty-four specimens being made. All hooks tested in this survey were embeded in 6" x 9" x 12" specimens, see Figure IV, in order to insure proper coverage for the steel. This size specimen was determined according to the 1940 J. C. C. Specifications.

The specimens containing the embeded steel were allowed to set in the forms in the laboratory air for the first twenty-four hours. After this period, the forms were removed and the specimens were placed in the moist-curing room and left for twenty-eight days since both strength concretes were designed as twenty-eight day strengths. The compression test specimens were also cured likewise.

The concrete mixes were designed as recommended in the Portland Cement Association pamphlet. The following design was then used for the 3000 psi concrete in this survey:

Coarse aggregate: Gravel with maximum particle size of 1 inch, free moisture of 1 per cent

Fig. III

Types of Hooks Used in Test

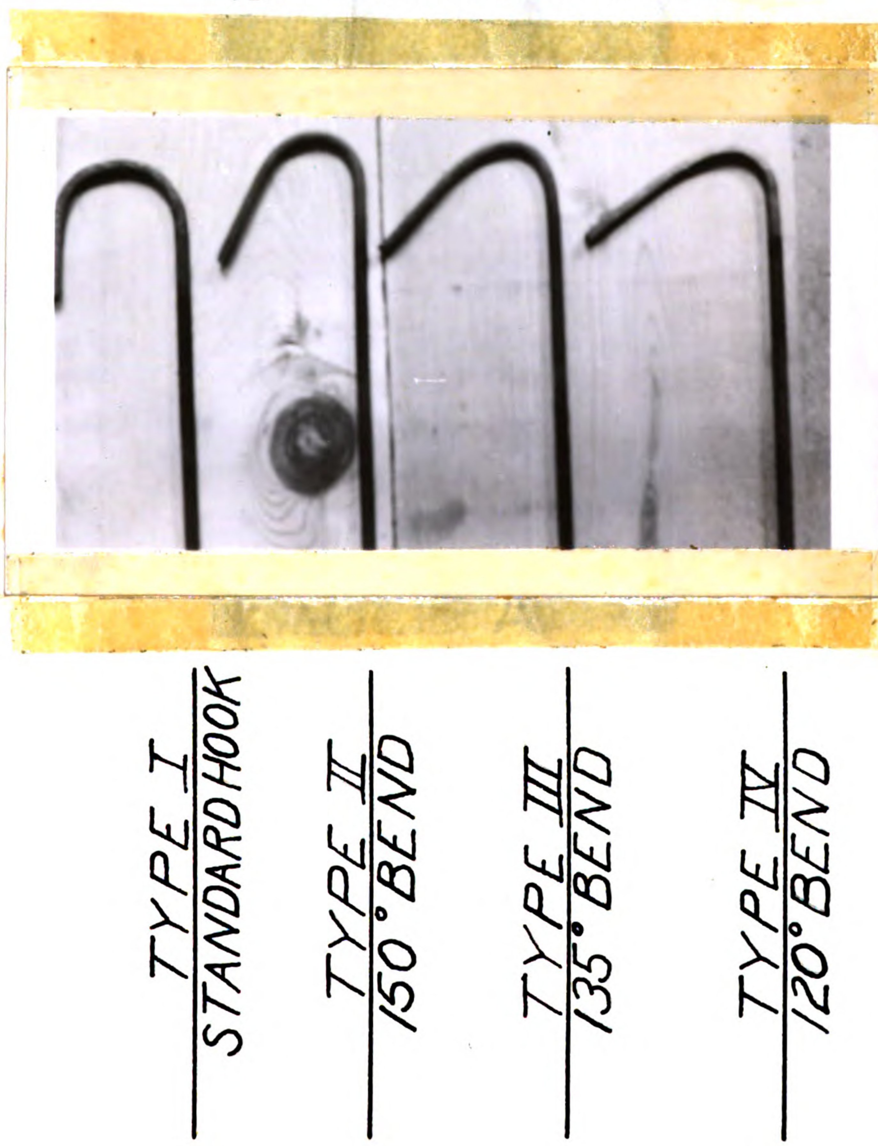


Fig. IV

Typical Specimen With Embeded,
Hooked, Steel Reinforcing Bar

and specific gravity of 2.65

Fine aggregate : Medium sand, free moisture of 3 per cent and specific gravity of 2.65.

Percentage of fine aggregate: 42

Water-cement ratio: 7 gal. of water/sack of cement or .62.

2 inch slump

Resulting in a mix by weight of 1: 2.9: 4.1 and a water-cement ratio of .49.

The same method was also used in the design of the 4000 psi concrete resulting in a mix by weight of 1: 2.1: 3.3 and a water-cement ratio of .51. Both mixes were slightly over-designed as the strength of the cement used had been running low in previously performed tests in the concrete laboratory.

Upon the completion of the 28-day curing period in the moist-room, all of the test specimens were removed and allowed to dry in the laboratory air. Each specimen containing a hooked bar was then tested by means of the Riehle universal testing machine in the Materials Testing Laboratory. See Figure V. This was accomplished by placing the specimen in an inverted position on the upper and stationary crosshead of the testing machine. See Figure V . In placing it in such a position, the portion of the bar that was protruding from the specimen passed down through the center of the upper crosshead and into a pair of jaws that were set in the lower and movable crosshead. After the jaws were adjusted so that

Fig. V

Method Used for Clamping Steel Reinforcing Bars in Riehle Universal Testing Machine they would have a firm grip on the bar, the machine was started and the lower crosshead was run downward at a rate of .05"/min. Thus a tensile force was exerted on the bar.

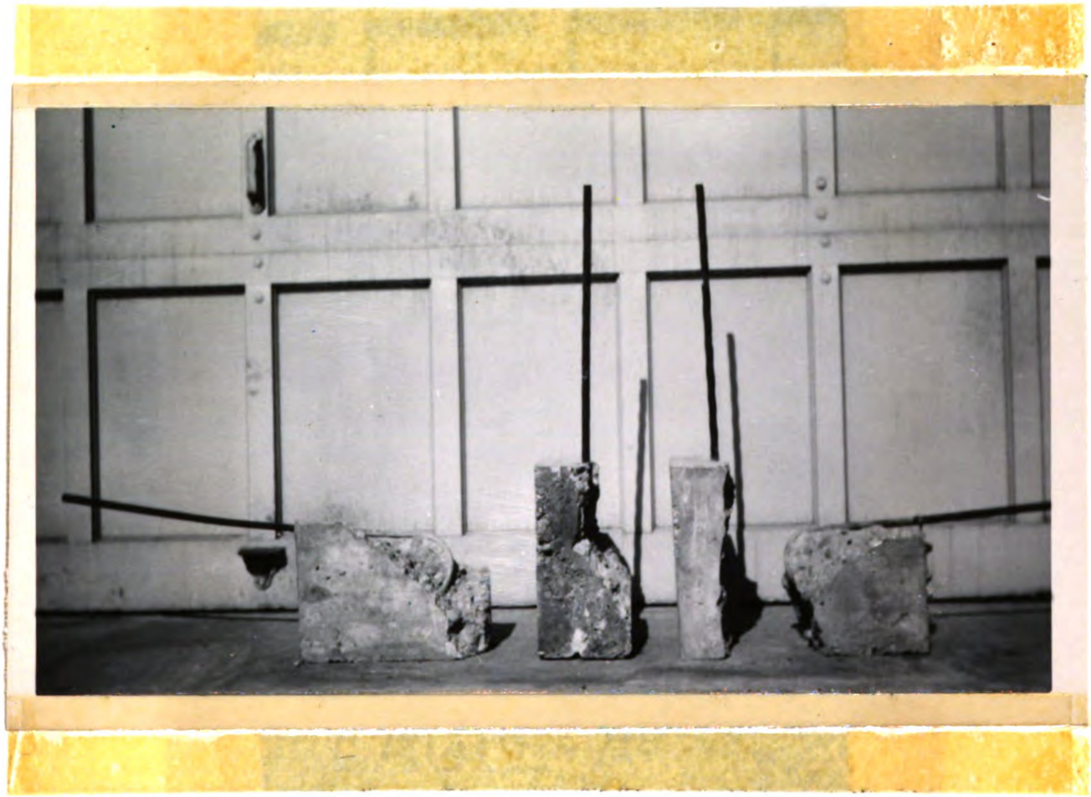
# CONCLUSION

By referring to the data sheet for the specimens containing the 3/8" bars it can readily be seen that the steel bars fractured due to tension in every case tested. This failure occurred outside the regions of the hook and the concrete and there was no straightening of the hook or crushing or cracking of the concrete. Each bar elongated until it reached its yield point and then it fractured. It is impossible to make a comparison of the strengths of the hooks from such results. However, it can be said that the hooks plus the bond between the steel and the concrete were stronger than the steel bars and because of this it would be satisfactory to use any of the types of hooks tested in this survey when using a 3/8" bar in either of the two concrete mixes.

With reference to the data sheet for the 1/2" bars, an inspection will show that the concrete fractured in every case tested. However, the types of fracture were not the same for the various hooks involved. Figure VI shows the different ways the concrete split. The only consistent type of split for both mixes was that of the specimens containing the standard or Type I hooks. This is shown in both Figure VII and Figure VIII. As can readily be seen from the figures, those specimens with the standard hooks embeded in them fractured in a vertical direction, splitting the specimens through the middle, while the other specimens containing the other various types of hooks, cracked and fractured in a diagonal direction. None of the bars showed

Fig. VI

Various Types of Splits



TYPE IV / 120° BEND

TYPE II / 150° BEND

TYPE I / STANDARD HOOK

TYPE III / 135° BEND

Fig. VII

Typical Split of Specimen Containing
Hook Type I or Standard Hook

Fig. VIII

Comparison of Splits Between

Hook Type I and II


TYPE II / 150° BEND

TYPE I / STANDARD HOOK

any signs of slippage during the application of the tensile force. Also, there was not any indication of a straightening of the hooks. From this data as well as that from the 3/8" bars it can be concluded that the hooks tested would definitely be satisfactory as far as the strength of the hook is concerned. However, there are other considerations involved that should be investigated.

All of the hooks tested in this survey, other than the standard hook, were acute angle hooks as shown in Figure III. The specimens containing the standard hook resisted the largest tensile force while only a slightly smaller force was required to fracture those with the type IV hook embeded in them. Also, the specimens containing the type II hooks required a slightly larger force than those with the typeIII hooks; yet, a smaller force than that required to fracture those containing the type IV hooks. In making these statements, it has been assumed that the specimens containing the "short bars" would have compared favorably with the corresponding hooks of the other mix. The reason for not testing the specimens with the "short bars" was that the length of the bars was not sufficient for the jaws to clamp firmly on them and, as a result, the bars slipped out of the jaws before any fracture occurred.

A plausible explanation for the specimens with the standard hooks embeded in them requiring a larger tensile force than any of those with the acute angle hooks may be that the acute angle hook tends to cause a greater compressive stress inside the bent portion of the bar than does the right angle hook. However, when the standard hook is used, there is a sufficient amount of concrete area inside the bent portion of the bar to withstand the compression that is developed.

The standard 6" x 12" compression test specimens were tested in the compression testing machine in the concrete laboratory. See Figure IX . As shown by the results of the compression tests in this survey, the mixes tested a little under their designed strength even though they were slightly overdesigned as previously stated in this paper. This does not have any significant result on the data obtained in this survey other than the fact that the concrete would have withstood a greater amount of compression before fracturing. If this had been the case, perhaps the steel would have fractured instead of the concrete.

The object of this thesis was not to attempt to revise the present method of design for hooked anchorage of steel reinforcing bars. It was to see how other types of hooked anchorage would compare with the present standard type and perhaps produce a more simple hook for construction purposes.

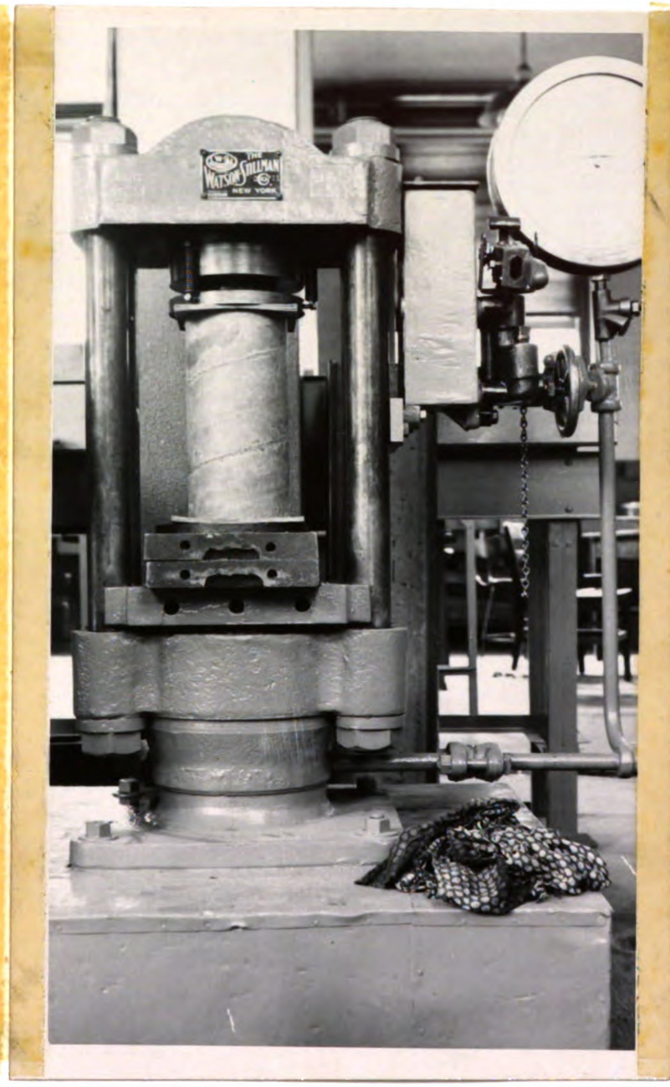



Fig. IX

Compression Testing Machine With

Typical Standard Compression

Test Cylinder

Tabulated Data

Compression Test of Concrete

| Design Strength (psi) | Load (lb) | Ultimate Compressive Strength (psi) Actual | Average |
|---|---|---|---|
| 3000 | 81,500 | 2890 | |
| | 83,500 | 2960 | |
| | | | 2925 |
| 4000 | 89,000 | 3150 | |
| | 94,000 | 3330 | |
| | | | 3240 |

Data for 3/8-inch Bars

Tensile Test for Hooks

| Design Strength of Concrete (psi) | Type of Hook | Load (lb) | Type of Failure |
|---|---|---|---|
| 3000 | I | 9430 | Steel |
| | II | 9990 | Steel |
| | III | 9330 | Steel |
| | IV | 9580 | Steel |
| 4000 | I | 9590 | Steel |
| | II | 10,260 | Steel |
| | III | 9390 | Steel |
| | IV | 9440 | Steel |

Note: See figure III for types of hooks.

Compression Test of Concrete

| Design Strength (psi) | Load | Ultimate Compressive Strength (psi) | |
|---|---|---|---|
| | | Actual | Average |
| 3000 | 77,000 | 2730 | |
| | 79,000 | 2800 | |
| | | | 2765 |
| 4000 | 95,500 | 3380 | |
| | 91,000 | 3220 | |
| | | | 3300 |

Data for 1/2-inch Bars

Tensile Test for Hooks

| Design Strength of Concrete (psi) | Type of Hook | Load | Type of Failure |
|---|---|---|---|
| 3000 | I | 19,340 | Concrete |
| | II | 15,720 | Concrete |
| | III | 13,210 | Concrete |
| | IV | Short Bar | None |
| 4000 | I | 20,480 | Concrete |
| | II | Short bar | None |
| | III | 13,490 | Concrete |
| | IV | 20,130 | Concrete |

Note: See Figure III for types of hooks.

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