AN EXPERIMENTAL STUDY OF HOOK ANCHORAGE FOR REINFORCING BARS

Thesis for the Degree of B. S.
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An Experimental Study of Hook Anchorage for Reinforcing Bars

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by

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THESIS

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July, 1939 C. A.

CONTENTS

INTRODUCTION

The Designing Engineer, figuring the reinforcing bars to be placed in a concrete structure, must, during the course of his investigations, do two things:

(1) Determine the size and number of bars needed to supply sufficient bond between the steel and concrete.

(2) Determine the length of bar necessary to furnish sufficient anchorage so that the bar will not be pulled from its original position.

After finding the final length of the straight bar, a hook is put in the end as an added measure of safety. In general practice this hook is of standard size determined by the size of the bar. The dimensions of the hook will be discussed in detail later.

When studying Reinforced Concrete, nothing was ever said as to how much of the total strain was taken by the hook, or its actual strength. The necessity of writing a thesis gave an excellent opportunity for investigation, and upon inquiring, nothing was found to signify that work had been done to any extent along these lines.

It was therefore determined that the object of this paper would be to test the standard sizes of hooks by embedding them in concrete, curing the specimens, and exerting a tensile force on the bar until there occured one of the four following failures:

(1) Straightening of the hook.

(2) Crushing the concrete.

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

(4) A combination of the above three.

Due to a limit on time and materials, it was possible to use only one mix of concrete, therefore, a complete set of data could not be obtained. If time had been allowed, different lengths of bars, and perhaps a different dimension of hook could have been used in these tests.

CHAPTER I

General Theory of Anchorage

Anchorage, for tension steel, begins only after the bars have passed out of the tension regions.[1] Therefore the amount of anchorage is left to the discretion of the designing engineer.

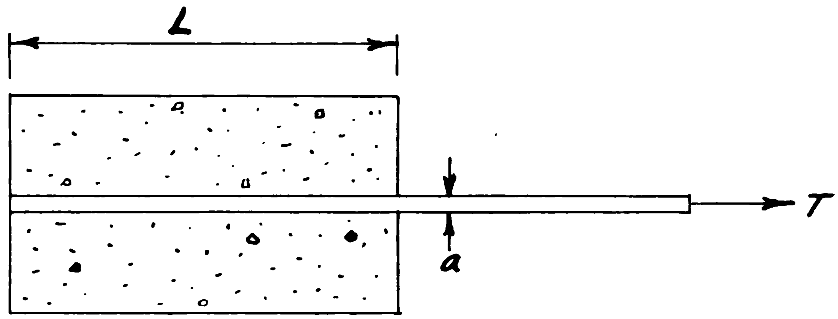

Fig. 1

Round Bar:

When f_s equals the fiber stress of the steel and "a" the diameter of the round bar or the sides of the square bar,

$$T = f_s A_s = fS \pi \frac{a^2}{4}.$$

To prevent force T from causing the bar to slip, T must be balanced by a bond force between the steel and concrete.

[1] Dean Peabody, Jr. " The Design of Reinforced Concrete Structures". New York: John Wiley & Sons Inc. 1936. Pp 40

Let u equal the bond stress,

then: Bond force $= u \times$ surface area of bar

$$= u \times \pi a L$$

and:

$$T = \text{Bond force}$$

therefore:

$$f_s \pi \frac{a^2}{4} = u \pi a L$$

$$L = \frac{f_s a}{4u}$$

Square bars:

$$T = f_s A_s = f_s a^2$$

$$\text{Bond force} = u L 4 a$$

then:

$$f_s a^2 = 4 u L a$$

therefore:

$$L = \frac{f_s a}{4u}$$

This equation for finding L is the same for both square and round bars.

Negative Steel:

Specifications state that any member of a rigid frame, shall have a length of anchorage beyond the face of the supporting member sufficient to develop the full maximum tension at an average bond stress of not greater than .04 f'_c for plain bars, and not more than .05 f'_c for deformed bars.

Positive Steel:

The anchorage for positive steel must be extended at least 10 bar diameters past the face of supports.[1]

Note: f'_c = ultimate compressive strength of concrete at 28 days.

[1] Ibid., Pp. 412

CHAPTER II

Description of Apparatus

Figure two gives the dimensions of the standard hooks used in this experiment.

Fig. 2.

The diameter of the bar itself determines the radius of the hook, as well as the tangent length on the end of the hook.

D = Bar Diameter.

A test bar three foot long was chosen as a convenient length, and the hook placed in the end.

In order to give all bars of the same size an equal chance, and in order to test only the strength of the hook itself, the bond between the steel and concrete was destroyed along the shaft beginning at point 1, the point of tangency to the semicircle. This was accomplished in two different ways as follows:

1. Plain bars--oiling the shaft with a medium weight of grease.
2. Deformed bars--oil alone on deformed bars would not allow the shafts to be free, so they

were wrapped with heavy paper
as well.

Both of these methodd effectively destroyed all of the bond as was in evidence when the specimens were broken.

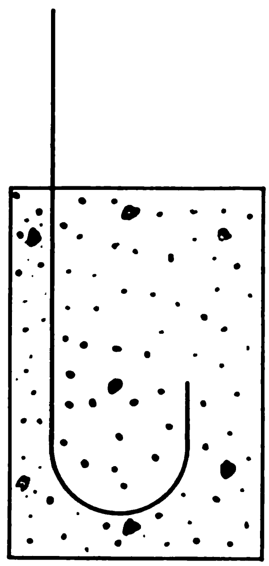

Fig. 3.

Figure 3 gives a cross-sectional view showing how the bar was placed in the concrete. At least three inches allowance was left between the bar and the edge of the specimen to give a good bond as well as good strength.

In bars up to 3/8 " inclusive, the specimen was made in the regular 6" cylinders used for compressive strength tests. With bars of larger sizes it was necessary to build forms so that the three inch clearance could be maintained.

Choosing a proper mix of concrete to give the best average strength tended to present another major problem. It was finally decided that a concrete mix of between 2500 and 3000 lbs. per square inch compressive strength would suit the problem, so towards that end the following mix was designed:

Water Cement Ratio: 6 to 1

Mix by Vol.:	Cement	Sand	Gravel
	1	2	3

The sand weighed 112 lbs. per Cu. ft., and the gravel 114 lbs. per cu. ft.. A slump of between $1\frac{1}{2}$ and 5 inches gave the desired strength at 28 days.

After the specimens had acquired their initial set, they were removed from the forms and placed in a water-vapor room and allowed to remain there for the full 28 days. The shafts of the bars which stood out from the concrete were rubbed with an oiled cloth at frequent intervals to prevent corrosion.

The machine used to break the specimens was a Riehle materials tester made in Philadelphia. It was composed of a stationary upper jaw, and a moveable lower jaw. The upper jaw was removed, the specimen to be tested inverted, and the bar placed through the opening left by the removal of the upper jaw. The moveable lower jaw was then clamped to the bar, and pressure applied until failure took place. The breaking force came from a hydro pressure pump, and the force recorded on a beam scale.

CHAPTER III

Investigation

Upon completion of the 28 day period of curing, each specimen was removed from the water-vapor room and prepared for breaking by drying the rods and removing the grease.

The specimens were then fractured and the data on the following pages was recorded. An inspection will show that in all but one case the fracture which took place was due to failure of the bar itself in tension, outside the regions of the hook, and not a crushing of the concrete or straightening out of the hook.

DATA

No.	Date	Slump	Load	Loading	Fracture
1/4 inch plain round					
A-1	5/4	1½"	3,005	Tension	Steel
A-3	"	"	2,855	"	"
A-4	"	"	2,720	"	"
A-5	"	"	3,055	"	"
A-6	"	"	2,905	"	"
A-7	5/9	3"	2,720	"	"
A-8	"	"	2,825	"	"
A-9	"	"	2,525	"	"
A-10	"	"	3,020	"	"
A-12	"	"	2,750	"	"
3/8 inch square deformed					
B-1	5/9	1½"	8,110	Tension	Steel
B-3	"	"	8,370	"	"
B-4	"	"	8,420	"	"
B-5	"	"	8,395	"	"
B-6	"	"	8,470	"	"
B-8	"	"	8,220	"	"
B-9	"	"	8,410	"	"
B-10	"	"	8,275	"	"
B-11	"	"	8,150	"	"
B-12	"	"	8,150	"	"

No.	Date	Slump	Load	Loading	Fracture
1/2 inch round deformed					
C-1	5/15	1½"	13,700	Tension	Steel
C-2	"	"	13,[illegible]75	"	"
C-3	"	"	13,820	"	"
C-4	"	"	14,320	"	"
D-1	"	5"	14,080	"	"
D-2	"	"	14,920	"	"
D-3	"	"	13,610	"	"
D-4	"	"	13,930	"	"
E-1	"	2"	14,775	"	"
E-2	"	"	13,830	"	"
1/2 inch square deformed					
E-3	5/15	2"	19,100	"	"
E-4	"	"	19,230	"	"
F-3	5/16	3"	19,310	"	"
F-2	"	"	19,120	"	"
F-4	"	"	19,330	"	"
G-1	5/18	5"	19,460	"	"
G-2	"	"	18,870	"	"
G-4	"	"	19,340	"	"
H-1	"	1½"	18,760	"	"
H-4	"	"	19,120	"	"

No.	Date	Slump	Load	Loading	Fracture
5/8 inch round deformed					
F-1	5/16	3"	22,120	Tension	Steel
G-3	5/18	5"	23,220	"	"
H-2	"	1½"	22,550	"	"
H-3	"	"	22,870	"	"
I-1	"	2"	23,160	"	"
I-2	"	"	22,100	"	"
I-3	"	"	22,760	"	"
I-4	"	"	23,450	"	"
1 inch square deformed					
None	5/11	3"	43,475	Concrete failed here.	
Cylinders for compressive strength					
A-2	5/4	1½"	112,500	Comp.	Concrete
A-11	5/9	3"	62,500	"	"
B-2	"	1½"	100,000	"	"
B-7	"	"	70,000	"	"
D-5	5/15	5"	39,000	"	"
D-6	"	"	90,000	"	"
E-5	"	2"	35,000	"	"
E-6	"	"	45,000	"	"
E-7	"	"	37,050	"	"
* G-5	5/18	5"	36,000	"	"

* 4" by 8" cylinder, strength equals 2,860 lbs/sq. in.

No.	Date	Slump	Load	Loading	Fracture
H-5	5/18	1½"	86,000	Comp.	Concrete
H-6	"	"	102,500	"	"
I-5	"	2"	47,500	"	"
I-6	"	2"	72,500	"	"

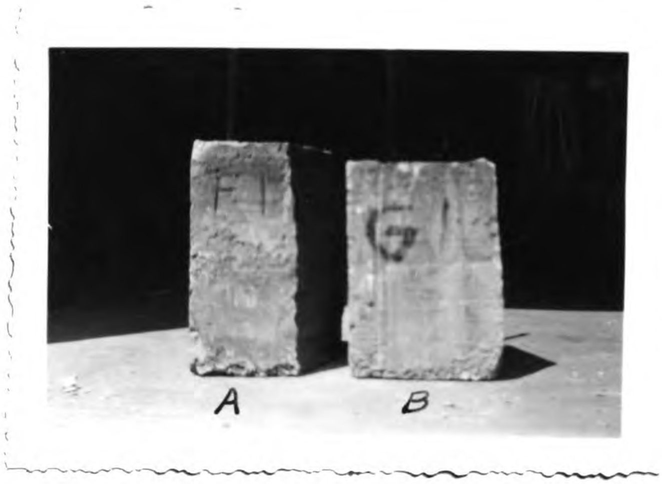

Fig. 4

Figure 4 shows two typical specimens used in this investigation.

Specimen No. F-1 in part A had already been broken, but the point of fracture was not shown in the picture. The rod stretched until the yield point was reached, and then parted. The cross-sectional area of the bar at the point of fracture was much smaller than the cross-sectional area of the rest of the bar.

Specimen No. G-1 in part B illustrates a typical test bar before fracture. An inspection of all the broken specimens revealed no cracks or failures of any kind in the concrete.

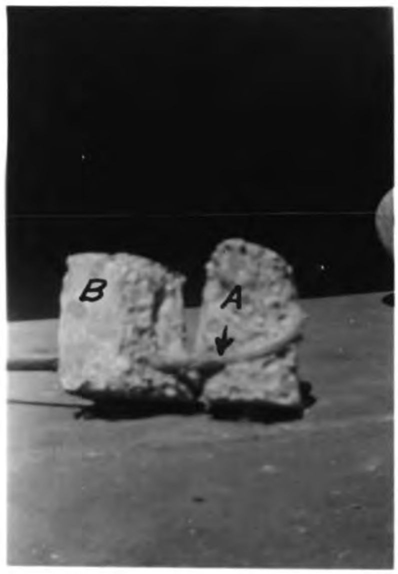

Fig. 5

Figure 5 shows one of the tested specimens which had been broken open to show the bond on the hook, and to see how effectively the bond on the shank had been destroyed. At point A is shown where the paper wrapping begins so as to protect the shank. How well it did its work was shown as the entire piece of concrete, labeled as "B", could be moved to any position on the bar.

The hook to the right of point "A" was still well bonded to the concrete.

In only one case did the concrete fail before the bar, and that was with a one inch square deformed bar. A view of this is shown in Fig. 6 on the next page.

Fig. 6

Above point "A" in figure 6, can be seen the protective paper covering around the shank of the bar. Here again is another proof of the effectiveness of this method of destroying the bond. In this test the concrete failed before the bar broke because of unequal pressure on the concrete. This caused the bar to spring outward in the direction of the piece which broke off, putting the concrete under tension. The bond between the hook and the concrete had not been destroyed and gave no evidence of failure in that direction, although the ultimate strength of the steel bar had almost been reached.

Conclusion

The purpose of this thesis was not to revise the anchorage design for reinforcing bars, or to determine a new method of anchorage, but to see how effectively the present design accomplished its purpose, and in some cases make possible a saving of reinforcing steel. Not saying, however, that this could be accomplished with the relatively small amount of research done here, but further investigation might make it possible to economize on large construction jobs. It has been shown in this thesis, as far as was accomplished, that the anchorage hook was stronger than the bar itself.

The following are examples showing how much could be saved on reinforcing steel by using the results shown in this paper:

Example 1.

$$u = .05\ f'_c = .05 \times 2{,}000$$
$$= 100$$
$$L = \frac{f_s\ a}{4\ u} = \frac{20{,}000 \times 1}{4 \times 100}$$
$$= 50'' \text{ past face of support}$$

New length:

$$L = 2 \times 3\ D + \frac{2\ \pi\ r}{2}$$
$$= 6 \times 1 + 4\ \pi\ 1$$
$$= 6 + 12.56$$
$$= 18.56''$$

Saving 31.44" reinforcing bar.

Example 2.

$$u = .05\ f'_c = .05 \times 3000$$

$$= 150$$

$$L = \frac{f_s\ a}{4\ u} = \frac{20,000 \times \frac{1}{2}}{4 \times 150}$$

$$= 16.67'' \text{ past face of support}$$

New length:

$$L = 2 \times 3\ D + \frac{2\ \pi r}{2}$$

$$= 6 \times \tfrac{1}{2} + \frac{4\ \pi}{2}$$

$$= 3 + 6.28$$

$$= 9.28''$$

Saving 7.39" reinforcing bar.

Much more work must be done, however, before a definite rule could be stated to decrease the present anchorage design. All designs of concrete must be tested as well as all sizes of bars before we can be certain that a new design would work as effectively as the present set up.

ROOM USE ONLY