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Looped Wire

for

Concrete Reinforcement

Adrian R. Legault

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Looped Wire for Concrete Reinforcement

ADRIAN R. LEGAULT

WITH THE present-day trend toward the construction of low-cost housing units to relieve the acute situation of inadequate housing in large cities, the problem of fireproof construction becomes vital. Fireproof construction in rural communities and villages is of equal importance, because when fire occurs there the loss is usually a total one, owing to the inadequacy of fire-fighting apparatus.

Since many fires in dwellings originate in basements, fireproof first floors to act as barriers to prevent the spread of basement fires to the living quarters above would be a big step toward fireproof construction. Concrete floors are a solution of this phase of the problem, provided their cost can be reduced to a figure which will make them feasible for small residences. The comparatively recent introduction of pre-cast concrete joists has been a step in the right direction, but before the concrete floor can be widely used in small houses the cost must be still further reduced. This reduction may be accomplished by greater efficiency in joist design, involving a reduction in the amount of steel necessary for adequate reinforcement; more efficient manufacturing methods; and more efficient methods of construction. It was with the first of these in mind—more efficient joist design—that this study was undertaken.*

A theoretical consideration of the design of joists indicates a possible reduction of steel costs of approximately 50 percent by the use of ordinary bright, basic wire at a working stress of 30,000 pounds per square inch as is now allowed in the American Concrete Institute Code, and a still greater saving by the use of high tensile-strength steel which would permit steel stresses double those permissible in ordinary reinforcing bars.

There has been some research in the use of high elastic-limit or high tensile-strength steel bars and wires. In this research many questions have been raised, some of which follow†: Is the lack of ductility of the high elastic-limit steel a serious drawback? Is there danger of cracks or fissures in the reinforcing bars or of rupture due to impact loading on the completed member? Since cold-drawn wire has a low bond resistance, does this place it at a distinct disadvantage? How may different grades of high elastic-limit steel be easily identified to prevent confusion? "*The possibility of insufficient anchorage for reinforcing bars probably constitutes the greatest present hazard in reinforced concrete design*†." Can the need of more effective anchorage be satisfactorily met to safeguard the use of higher stresses in the steel?

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*The help and advice of Mr. J. K. Selden in carrying on this investigation and the assistance of Mr. C. A. Hagelin in organizing the data are gratefully acknowledged.

†H. J. Gilkey, G. E. Ernst, Proc. 14th Ann. Meet., Highway Research Board.

A consideration of these questions indicates the possibility of the use of high elastic-limit wire wound in a continuous loop, as illustrated in figure 1, for reinforcing concrete as a means of satisfactorily answering them. The small diameter of wire eliminates the necessity of sharp bends and therefore minimizes the effect of a lack of ductility. The large number of wires as compared to the larger diameter bars makes almost negligible the possibility of a failure due to a flaw in any one wire. The larger surface area of a number of small wires as compared with a few larger bars will help to compensate for the lower bond resistance of the wire. Identification of individual bars as to grades by some means of marking presents a problem. The tagging of a large coil of wire, however, would be

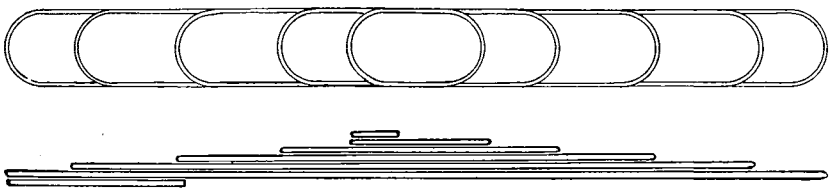

Figure 1.—Proposed method of reinforcing a precast concrete member with a continuous loop of cold-drawn wire. Above, top view; below, side view.

a simple means of denoting its grade. If the reinforcing steel is wound in a continuous loop or coil and the last coil anchored at the end, there should be no slippage, even though the bond resistance is very low.

Professor T. D. Mylrea* has performed some interesting experiments on T-beams reinforced by a large number of small rods bent and anchored according to the "Scott system." Exceptionally high bond and shear values were developed. The steel was stressed in excess of its yield point of 96,000 pounds per square inch.

In contrast, beams reinforced with conventional ¾-inch bars with hooked ends failed at less than half the load taken by the other beams, due to the splitting action of the hooks. Strain readings indicated a breaking down of the bond as the load increased. In this connection Professor Mylrea says, "It is obvious that while bond may be depended upon at low stresses it is not capable of developing those high steel stresses which would prove so economical with high elastic-limit steel now available. Anchorage is therefore necessary."

While the "Scott system" of anchorage appears to be adequate insofar as anchorage is concerned, it has the disadvantage of added cost because of the use of the special anchors and the threading of the extra hard steel bars to receive them. Another disadvantage from

*Mylrea, T. D., "Tests of Reinforced Concrete T-Beams," Jnl. Amer. Concrete Inst., May-June 1934, p. 448.

the cost viewpoint is that steel rods having a yield point of 96,000 pounds per square inch are not readily available at the price of ordinary reinforcing bars.

Again, the advantages of cold-drawn wire with looped anchorage seem apparent. With cold-drawn wire, the drawing operation increases the yield point. Wire with an ultimate strength of 125,000 pounds per square inch may be ordered in 1,000-pound lots at approximately the same cost as reinforcing bars. The cost of any special method of anchorage is eliminated by the anchorage of the looped ends of the continuous coil.

This type of reinforcement appears to lend itself especially well to reinforcing pre-cast joists. The tension- and shear-resisting portions of the coil may be embedded in the pre-cast joist, while the looped ends are left projecting to be embedded in the cast-in-place floor slab. In this manner a continuity of steel from joists to slab may be obtained.

Other advantages from the viewpoint of manufacture are these: (1) One or two sizes of wire could be ordered in quantity to supply reinforcement for any size and loading of joists; reinforcing bars require special orders for different conditions; (2) bending up the ends of part of the loops would provide shear reinforcement and eliminate the necessity of fabricating and attaching separate stirrups.

Apparently there has been no research in the possibility of reinforcing concrete with looped wire. An attempt is made, therefore, in this study to obtain data on some of the fundamentals involved, in order that more extensive research may be carried out in a later project. This paper, then, is largely a report on an exploratory study, with one of its objectives that of encouraging more research in this field.

Problems in Design

When a large number of small wires are substituted for a few of the larger reinforcing bars, close spacing or even direct contact becomes necessary. What is the minimum spacing possible without seriously affecting bond resistance and efficiency of the reinforcing steel?

In order to compensate for the lower bond stress allowable in cold-drawn wire and to permit the use of high steel stresses, some form of mechanical anchorage becomes necessary. What steel stress will looped anchorage develop? What diameter of loop and depth of embedment is most efficient?

After the coil has been wound, the ends must be anchored. How may this be accomplished simply and effectively?

A substantial saving can be made in the manufacture of pre-cast members if the quantity of steel necessary for adequate reinforcement can be reduced 50 percent or more. Is it possible to effect this saving by the use of a loop of high elastic-limit steel having only

half the area necessary for balanced reinforcement with conventional reinforcing bars?

These problems served as a basis for the tests made in carrying on the project herein reported.

General Procedure

The project was divided into four series consisting of investigations primarily for the purpose of answering the questions, at least in part, which are outlined under "Problems in Design." Specimens were cast and tested for each series. The report is made upon each series in order.

Series I

The purpose of this series was to determine the minimum vertical and horizontal spacing of small, smooth wires, without decreasing their effectiveness as tension reinforcement. This determination was necessary because, as previously pointed out, close spacing is essential. The use of wire reinforcing in joists would necessitate the crowding of from 5 to 50 strands of wire into a 2-, 3-, or 4-inch joist width. Obviously then, the conventional rules for spacing cannot be used.

Procedure

Number 3 gauge and number 8 gauge cold-drawn wire was used in this series. The two sizes of wire had diameters of 0.2437 inch and 0.1620 inch, respectively. All wires were 12 inches in length and straight. The test pieces were cast in wooden forms. They were 18 inches long and 5 inches high, and they varied in width. The wires were spaced as desired by drilling spaced holes in a ¾-inch

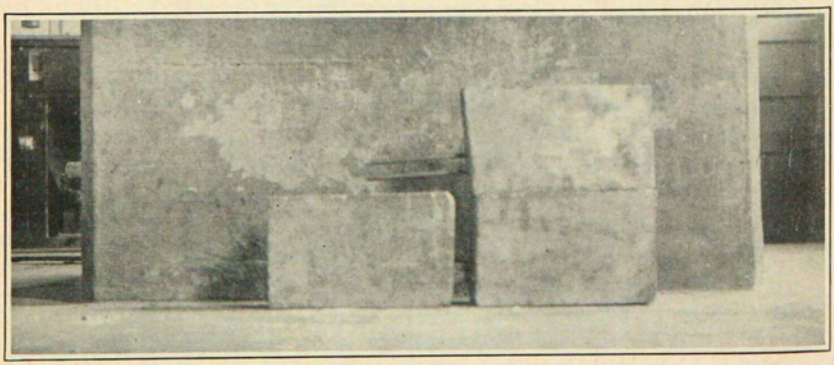

Figure 2.—Some specimens in series I before and after being tested.

wooden block into which the wires were inserted. The wires were so placed that approximately 4½ inches projected on one side of the block and 7 inches on the other. The block containing the wires was then placed in the center of the form, and the test piece was cast. The result was two concrete blocks 8⅝ inches by 5 inches, variable in width, held together by the wires which were exposed for ¾ inch between blocks where the wooden dividing piece had been removed. There was 1 inch of concrete below the bottom wire in all specimens. This design gave a specimen simulating actual conditions in a joist.

The concrete for this series was designed to have a strength of 6,000 pounds per square inch at the end of 4 days. A high early-strength cement and $CaCl_2$ were used. Vibration was used in placing the concrete in all series. The mix was 1:1½:1¾, with 5 gallons of water per sack of cement. The coarse aggregate had a maximum diameter of ½ inch.

Table 1 shows the results of pull-out tests on these specimens. Loads were taken after some slipping had occurred.

TABLE 1.—*Results of pull-out tests on specimens in series I.*

Specimens	Width	Diameter of wire	Number of tiers	Spacing of tiers	Wires per tier	Depth of embedment	Total pull	Average bond per square inch	Stress in steel per square inch
Number	*Inches*	*Inches*		*Inches*	*Number*	*Inches*	*Pounds*	*Pounds*	*Pounds*
1A	1	0.2437	1	..	2	4¼	660	101	7,100
1B	2	0.2437	1	..	4	4	2,160	176	11,600
1C	3	0.2437	3	½	3	4¼	4,300	147	10,200
1D	4	0.2437	3	1	3	4¼	5,280	181	12,600
1E	2	0.162	1	..	2	4½	670	145	16,300
1F	2	0.162	1	..	6	4	2,260	184	18,300
1G	3	0.162	3	½	6	4¼	5,200	133	14,100
1H	4	0.162	3	1	6	4¼	5,500	141	14,900

The resistance to pull, after the first slip, increased from 5,500 pounds to 6,000 pounds in specimen H. Specimen C failed by shearing off the concrete below the wires. This was likely due to an uneven pull on one of the shackles, which were designed to fit into the ¾-inch space between blocks so that a pull could be applied in the testing machine.

In all cases the wires pulled out of the concrete, and in no case was the spacing so close as to cause shearing off of the concrete between the wires from the surrounding concrete.

Table 2 shows the cylinder strengths when the tests were made. Cylinders 3 inches in diameter by 6 inches in height were used in all series.

TABLE 2.—*Cylinder strengths at the time of testing series I*.*

Cylinders	Total load	Strength per square inch
Number	*Pounds*	*Pounds*
1	39,000	5,520
2	42,000	5,940
3	45,000	6,360
4	49,000	7,060

*Cylinders 1 and 2 were tested at 4 days; cylinders 3 and 4 were tested when the tests on specimens were completed, on the fifth day after casting.

As a further check on the bond of cold-drawn wire, a set of specimens was made having only one wire embedded in a 4-inch by 4-inch block. The concrete had a cylinder strength of 2,800 pounds per square inch at the time the specimens were tested. Three sizes of wire were used. The depth of embedment was 4 inches in every case. The results of these tests are recorded in table 3.

TABLE 3.—*Results of bond test on single wires.*

Wire gauge	Load for bond failure	Surface area embedded	Unit bond stress at first slip	Ultimate unit bond stress
Number	*Pounds*	*Square inches*	*Pounds*	*Pounds*
3	380	3.06	124	192
3	330	3.06	108	244
8	380	2.04	187	187
8	300	2.04	147	147
12	200	1.33	151	376
12	180	1.33	136	376

The number 3 and number 12 wires were cold-drawn but not high elastic-limit, as was the number 8.

Conclusions

The low-bond stress for two wires, specimens A and E, was likely due to eccentric loading in the test. The wires in these two specimens had a ¾-inch vertical spacing. In all other specimens the wires were placed in vertical tiers, with no space between wires vertically.

The bond for four wires in a vertical tier and touching each other was about 75 percent of that found by Professor Gilkey for a single cold-drawn wire, and this checked very well with the results

on single wires recorded in table 3. It was also higher than for specimens A and E, in which the wires were not touching.

The unit bond for three vertical tiers was nearly the same as for one tier only. The unit bond was only slightly less for ½-inch spacing than for 1-inch spacing.

Cold-drawn wires may be placed touching each other without appreciably affecting the bond.

The bond strength is not appreciably affected by the strength of the concrete. This agrees with Professor Gilkey's findings.

Because of the close spacing of the reinforcement, the concrete must be placed by vibration.

Series II

Procedure

The purpose of this series was to determine what steel stress could be developed by embedding the looped wire in concrete and to find what diameter of loop and depth of embedment gave the most satisfactory results. This was done by embedding different diameter loops of wire to varying depths in concrete blocks and determining the pull necessary to cause the wire to break or the concrete to fail. Number 8 wire was used in this series as typical of the size likely to be used in joist reinforcement.

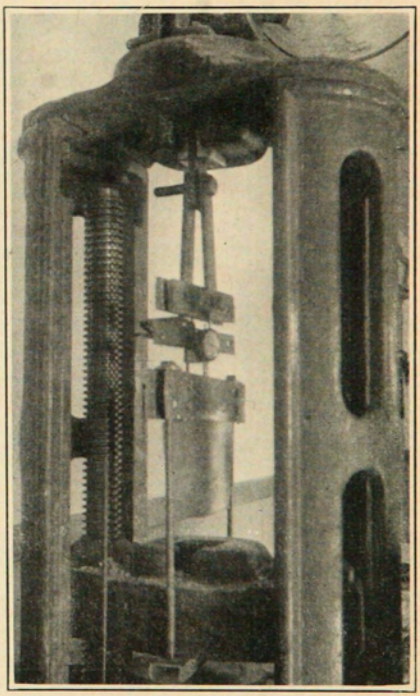

Figure 3.—A specimen of series II being tested.

Figure 3 shows the assembled pulling device for these tests. Figure 4 shows a specimen in the machine being tested. The results of the tests are recorded in table 4.

Results on specimens F22X, E44X, F44X, E44Y, F44Y, F22Y, and E44W, recorded in table 4, were not considered satisfactory, because the pull had been eccentric when they were broken. Another set of specimens having the wire ½ inch from the side of the block was made. In testing these, provision was made for maintaining a straight pull on the specimen. The results on this

TABLE 4.—*Results of pull-out tests on number 8-gauge wire with loops of varying diameter embedded to various depths in concrete blocks.*

Specimens	Designed strength of concrete per square inch	Diameter of loop	Depth of embedment	Size of block	Load to cause failure	Shear area	Shearing stress per square inch
Number	*Pounds*	*Inches*	*Inches*	*Inches*	*Pounds*	*Square Inches*	*Pounds*
A44W	6,000	4	4	6 x6	4,650	14.28	326
A44W	6,000	4	4	6 x6	*4,800	14.28	336
A24W	6,000	2	4	6 x6	4,800	7.57	635
A24W	6,000	2	4	6 x6	*4,400	7.57	581
A14W	6,000	1	4	6 x6	3,900	3.89	1,005
B42W	6,000	4	2	6 x6	4,620	6.28	736
B22W	6,000	2	2	6 x6	4,070	3.57	1,140
B21W	6,000	2	1	6 x6	2,700	1.57	1,720
B21W	6,000	2	1	6 x6	3,230	1.57	2,060
D22W	6,000	2	2	3 x3	4,000	3.57	1,120
D22W	6,000	2	2	3 x3	4,540	3.57	1,270
E44W	6,000	4	4	6 x6	†3,410	14.28	239
A64X	3,000	6	4	6 x6	4,440	20.13	220
A44X	3,000	4	4	6 x6	*4,690	14.28	328
A44X	3,000	2	4	6 x6	4,950	14.28	347
A24X	3,000	2	4	6 x6	3,600	7.57	475
A24X	3,000	2	4	6 x6	3,500	7.57	462
A14X	3,000	1	4	6 x6	2,880	3.89	740
B42X	3,000	4	2	6 x6	2,700	6.28	430
B22X	3,000	2	2	6 x6	3,270	3.57	916
B21X	3,000	2	1	6 x6	2,050	1.57	1,308
C44X	3,000	4	4	4¼ x4¼	4,360	14.24	306
C24X	3,000	2	4	4¼ x4¼	4,950	7.57	655
C42X	3,000	4	2	4¼ x4¼	3,540	6.28	564
C22X	3,000	2	2	4¼ x4¼	4,750	3.57	1,330
D22X	3,000	2	2	3 x3	3,710	3.57	1,039
D22X	3,000	2	2	3 x3	3,850	3.57	1,079
E44X	3,000	4	4	6 x6	†3,780	14.28	265
F44X	3,000	4	4	4¼ x4¼	†3,350	14.28	235
F22X	3,000	2	2	4¼ x4¼	†2,500	3.57	700
A64Y	1,500	6	4	6 x6	4,560	20.13	227
A44Y	1,500	4	4	6 x6	4,380	14.28	307
A44Y	1,500	4	4	6 x6	*4,330	14.28	304
A24Y	1,500	2	4	6 x6	3,580	7.57	473
A24Y	1,500	2	4	6 x6	2,270	7.57	300
B24Y	1,500	2	4	6 x6	2,840	7.57	375
B22Y	1,500	2	2	6 x6	2,590	3.57	725
B21Y	1,500	2	1	6 x6	*1,670	1.57	1,063
B21Y	1,500	2	1	6 x6	1 520	1.57	968
C44Y	1,500	4	4	4¼ x4¼	4,270	14.28	300
C24Y	1,500	2	4	4¼ x4¼	3,890	7.57	515
C42Y	1,500	4	2	4¼ x4¼	2,760	6.28	440
C22Y	1,500	2	2	4¼ x4¼	2,410	3.57	675
D22Y	1,500	2	2	3 x3	2,530	3.57	710
D22Y	1,500	2	2	3 x3	2,490	3.57	698
E44Y	1,500	4	4	4¼ x4¼	†1,880	14.28	103
F44Y	1,500	4	4	4¼ x4¼	†3,050	14.28	214
F22Y	1,500	2	2	4¼ x4¼	†1,800	3.57	505

*In these specimens the bond was destroyed by an initial pull on one wire only before they were tested. A pull of approximately 700 pounds was necessary to cause the bond to fail in all concrete strengths.

†The wire was placed one-half inch from the edge or face of the block in these specimens. In all others the wire was centered in the block. The results are not entirely accurate, because it was not possible to get a straight pull when testing; however, they may be used as an indication of the behavior.

TABLE 4 *(Continued).—Results of pull-out tests on number 8-gauge wire with loops of varying diameter embedded to various depths in concrete blocks.*

Specimens	Bearing area	Bearing stress per square inch	Splitting area	Splitting stress per square inch	Type of failure
Number	*Square inches*	*Pounds*	*Square inches*	*Pounds*	
A44W	0.648	7,180	24.00	194	Wire slipped in clamp
A44W	0.648	7,410	24.00	200	Wire broke
A24W	0.324	14,800	24.00	200	Wire broke
A24W	0.324	13,580	24.00	183	Wire broke
A14W	0.162	24,100	24.00	163	Wire broke
B42W	0.648	7,140	12.00	385	Wire broke
B22W	0.324	12,570	12.00	339	Split block in plane of wire
B21W	0.324	8,340	6.00	450	Broke at base of wire loop
B21W	0.324	9,960	6.00	538	Split out wedge of concrete
D22W	0.324	12,320	6.00	667	Wire broke
D22W	0.324	14,000	6.00	757	Wire broke
E44W	0.648	5,260	24.00	142	Corner of block split off
A64X	0.972	4,560	24.00	185	Wire broke
A44X	0.648	7,240	24.00	196	Wire broke
A24X	0.648	7,650	24.00	206	Wire broke
A24X	0.324	11,100	24.00	150	Block split
A14X	0.324	10,790	24.00	146	Block split
B42X	0.162	17,790	24.00	120	Pulled out concrete over loop
B22X	0.648	4,170	12.00	225	Split at base of loop
B21X	0.324	10,090	12.00	272	Block split
C44X	0.324	6,330	6.00	342	Broke piece from side of block
C24X	0.648	6,730	17.00	256	Wire broke
C42X	0.324	15,270	17.00	291	Wire broke
C22X	0.648	5,460	8.50	416	Block split at base of loop
D22X	0.324	14,630	8.50	559	Block split
D22X	0.324	11,430	6.00	618	Block split
E44X	0.324	11,880	6.00	642	Block split
F44X	0.648	5,840	24.00	158	Split off side of block
F22X	0.648	5,170	17.00	197	Broke off corner of block
A64Y	0.324	7,720	8.50	294	Split off side of block
A44Y	0.972	4,700	24.00	190	Block split
A44Y	0.648	6,690	24.00	181	Wire broke
A24Y	0.648	6,750	24.00	182	Block split
A24Y	0.324	11,060	24.00	149	Block split
B24Y	0.324	7,010	24.00	94	Block split along one wire
B22Y	0.324	8,760	24.00	114	Block split
B21Y	0.324	8,000	12.00	216	Block split
B21Y	0.324	5,150	6.00	278	Block split
C44Y	0.324	4,690	6.00	253	Block split
C24Y	0.648	6,600	17.00	251	Wire broke
C42Y	0.324	12,000	17.00	229	Block split
C22Y	0.648	4,260	8.50	325	Block split
D22Y	0.324	7,450	8.50	284	Block split
D22Y	0.324	7,810	6.00	421	Block split in plane of wire
E44Y	0.324	7,690	6.00	415	Block split in plane of wire
F44Y	0.648	2,900	17.00	110	Broke off upper corners of block
F44Y	0.648	4,707	17.00	180	Wire pulled out side of block
F22Y	0.324	5,555	8.50	212	Split off side of block

second group are shown in table 8. The blocks in this set were all 6 inches by 6 inches.

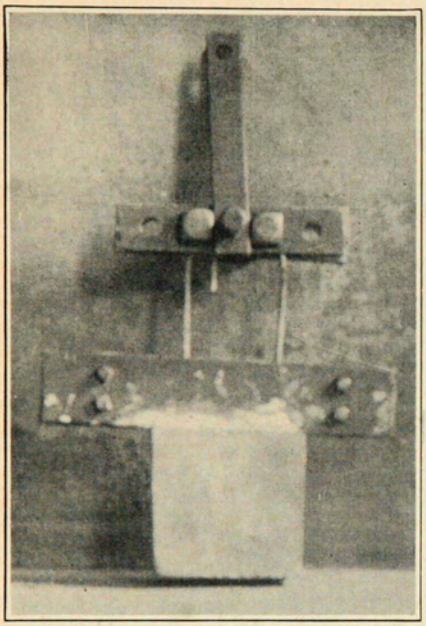

Figure 4.—Assembled pulling device for tests in series II.

As a supplement to the tests recorded in table 4, a set of specimens were made in which different sizes of wire were used. The number 8 wire was the same as that used in the main group in this series. Its ultimate strength was approximately 133,000 pounds per square inch. Its diameter was 0.1620 inch. The number 3 wire had a diameter of 0.2437 inch and an ultimate strength of approximately 83,000 pounds per square inch. The number 12 had a diameter of 0.1055 inch and an ultimate strength of approximately 95,000 pounds per square inch.

The results of these tests are recorded in table 9.

Conclusions

The minimum anchorage value for all number 8 wire loops of 2-inch diameter or more and a depth of embedment of at least 2 inches was 3,270 pounds, or 80,000 pounds per square inch, except in the 1,500-pound concrete and the 4-inch diameter loop with 2-inch embedment in the 3,000 pound concrete. The approximate value for the ultimate strength of ordinary cold-drawn mild steel wire is 80,000 pounds per square inch.

The anchorage of a 2-inch diameter loop with a 2-inch depth of embedment is sufficient to develop the ultimate strength of number 8 mild steel wire. A larger anchorage area should be used for high elastic-limit steel wire.

Anchorage by this method is practically independent of bond, as shown by those tests in which the bond was destroyed before testing.

The anchorage of 2- and 4-inch diameter loops apparently is almost independent of concrete strengths. The bond resistance is again shown to be unaffected by concrete strength.

In general, the depth of embedment should be sufficient to give a total coverage of the curve portion of the wire of at least 1 inch and preferably should be equal to the diameter of the loop. Increasing the depth of embedment is more effective than an increase in loop diameter as a means of raising the anchorage values.

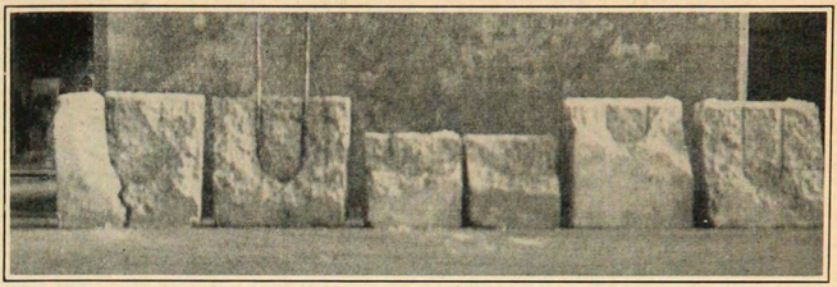

Figure 5.—Some specimens of series II after being tested.

The bearing stress on the concrete under the loop increases with decreasing loop diameters.

The ratio of maximum bearing stress to cylinder strength of the concrete increases with decreasing concrete strengths. Surprisingly high values were obtained.

In the 1,500-pound concrete, the size of block had no apparent effect. The relation of loop diameter and depth of embedment to strength were comparatively consistent. In stronger concrete there appeared to be some effect of block size, and the correlation of variables was less consistent.

Unit shearing stresses increased with smaller shear areas.

The strength of the concrete has little or no effect on bond, bearing stress, or splitting stress. The effect on bearing stress and resistance to shear and splitting is more apparent than the effect on bond, but the variation is not nearly in proportion to the compressive strength of the concrete.

TABLE 5.—*Cylinder strengths for 6,000-pound concrete in specimens recorded in table 4.*

Cylinders	Total load	Strength per square inch	
Number	*Pounds*	*Pounds*	
1	40,950	5,792	
2	40,560	5,737	Average 5,731
3	40,050	5,664	

TABLE 6.—*Cylinder strengths for 3,000-pound concrete in specimens recorded in table 4.*

Cylinders	Total load	Strength per square inch	
Number	*Pounds*	*Pounds*	
1	20,120	2,847	
2	19,700	2,786	Average 2,754
3	18,580	2,628	

TABLE 7.—*Cylinder strengths for 1,500-pound concrete in specimens recorded in table 4.*

Cylinders	Total load	Strength per square inch	
Number	*Pounds*	*Pounds*	
1	9,880	1,397	
2	9,240	1,307	
3	9,210	1,303	Average 1,316
4	9,180	1,298	
5	9,000	1,273	

TABLE 8.—*Results of tests of second group of specimens, with only one-half inch covering of concrete over wires on sides of blocks.*

Specimens	Designed strength of concrete per square inch	Diameter of loop	Depth of embedment	Size of block	Load to cause failure	Shear area	Shearing stress per square inch
Number	*Pounds*	*Inches*	*Inches*	*Inches*	*Pounds*	*Square inches*	*Pounds*
44X	3,000	4	4	6x6	4,500	14.28	315
24X	3,000	2	4	6x6	3,500	7.57	462
22X	3,000	2	2	6x6	2,400	3.57	672

TABLE 9.—*Results of tests when different sizes of wire were used.*

Specimen*	Designed strength of concrete per square inch	Diameter of loop	Depth of embedment	Size of block	Load to cause failure	Shear area	Shearing stress per square inch
Number	*Pounds*	*Inches*	*Inches*	*Inches*	*Pounds*	*Square inches*	*Pounds*
A14- 3	3,000	1	4	6 x6	4,200	3.89	1,080
A14- 8	3,000	1	4	6 x6	4,270	3.89	1,098
A14-12	3,000	1	4	6 x6	1,530	3.89	394
A22- 3	3,000	2	2	6 x6	2,550	3.57	715
A22-12	3,000	2	2	6 x6	1,550	3.57	435
A24- 3	3,000	2	4	6 x6	4,750	7.57	628
A24- 8	3,000	2	4	6 x6	4,700	7.57	621
A24-12	3,000	2	4	6 x6	1,700	7.57	225
A44- 3	3,000	4	4	6 x6	6,200	14.28	435
A44- 8	3,000	4	4	6 x6	5,000	14.28	350
D22- 3	3,000	2	2	3 x3	1,960	3.57	550
D22-12	3,000	2	2	3 x3	1,500	3.57	420
C22- 3	3,000	2	2	4¼ x4¼	2,330	3.57	654
C22-12	3,000	2	2	4¼ x4¼	1,500	3.57	420
C24- 3	3,000	2	4	4¼ x4¼	4,660	7.57	616
C24-12	3,000	2	4	4¼ x4¼	1,580	7.57	209
D12-12	3,000	1	2	3 x3	1,550	1.89	820
D21-12	3,000	2	1	3 x3	1,500	1.57	955

*Numbers following dashes in specimen numbers refer to gauge numbers of wire.

When a straight pull was obtained, ½ inch of covering on the side of the block gave the same results as when the wire was in the center of the 2½-inch width block for both 2-inch and 4-inch diameter loops and 4-inch embedment. In the specimen with 2-inch diameter loop and 2-inch embedment, the ½-inch covering was insufficient, as indicated by a lower stress for failure than when the loop was centered in the concrete block.

Surprisingly high anchorage values were obtained with only ½-inch cover, even when the loading was eccentric and the wire was

TABLE 8 *(Continued).—Results of tests of second group of specimens, with only one-half inch covering of concrete over wires on sides of blocks.*

Specimens	Bearing area	Bearing stress per square inch	Splitting area	Splitting stress per square inch	Type of failure
Number	*Square inches*	*Pounds*	*Square inches*	*Pounds*	
44X	0.648	6,950	24.00	187	Wire broke
24X	0.324	10,800	24.00	146	Concrete failed
22X	0.324	7,400	12.00	200	Concrete failed

TABLE 9 *(Continued).—Results of tests when different sizes of wires were used.*

Specimen*	Bearing area	Bearing stress per square inch	Splitting area	Splitting stress per square inch	Type of failure
Number	*Square inches*	*Pounds*	*Square inches*	*Pounds*	
A14- 3	0.2437	17,230	24.00	175.0	Wire broke
A14- 8	0.162	26,400	24.00	178.0	Wire broke
A14-12	0.1055	14,500	24.00	63.7	Wire broke
A22- 3	0.4874	5,240	12.00	212.0	Concrete failed
A22-12	0.2110	7,350	12.00	129.0	Wire broke
A24- 3	0.4874	9,750	24.00	198.0	Block shattered
A24- 8	0.3240	14,500	24.00	196.0	Block shattered
A24-12	0.2110	8,050	24.00	70.8	Wire broke
A44- 3	0.9748	6,360	24.00	258.0	Concrete failed
A44- 8	0.6480	7,720	24.00	208.0	Wire broke
D22- 3	0.4874	4,020	6.00	327.0	Concrete failed
D22-12	0.2110	7,100	6.00	250.0	Wire broke
C22- 3	0.4874	4,780	8.50	274.0	Concrete failed
C22-12	0.2110	7,100	8.50	177.0	Wire broke
C24- 3	0.4874	9,580	17.00	274.0	Concrete failed
C24-12	0.2110	7,490	17.00	93.0	Wire broke
D12-12	0.1055	14,690	6.00	258.0	Wire broke
D21-12	0.2110	7,100	3.00	500.0	Wire broke

*Numbers following dashes in specimen numbers refer to gauge numbers of wire.

TABLE 10.—*Cylinder strengths for concrete in specimens recorded in tables 8 and 9.*

Cylinders	Total load	Strength per square inch	
Number	*Pounds*	*Pounds*	
1	25,460	3,601	
2	25,400	3,592	Average 3,586
3	25,200	3,564	

pulled at an angle of from 5 to 10 degrees with the block. In these tests, steel stresses averaging 80,000 pounds per square inch were obtained.

In every case except one, the number 8 wire gave at least equal results to number 3, and in most cases better results.

The one exception of the number 8 wire being equal to the number 3 was a case of the wire failing. The failure of the wire was due to the load being unequally divided between wires. Had this not occurred, the number 8 wire undoubtedly would have taken as high a stress as the number 3.

The anchorage of the number 12 wire was sufficient to break the wire in every case.

A concrete area of 2 square inches under the loop is sufficient to develop the ultimate strength of the number 12 wire.

TABLE 11.—*Recommended loop sizes and embedment to develop given steel stresses.*

Concrete strength per square inch	Steel stress desired per square inch	Diameter of loop	Depth of embedment
Pounds	*Pounds*	*Inches*	*Inches*
6,000	80,000	1½	2½
6,000	100,000	2	2
6,000	120,000	3	4
3,000	80,000	2	2
3,000	100,000	3	4
3,000	120,000	4	4
1,500	80,000	2½	4
1,500	100,000	4	4
1,500	120,000	6	6

Series III

Procedure

To discover a practical method of anchoring the end of the wire after the coil is wound, pieces of the number 8 wire were deformed at the end in different ways, embedded in concrete blocks, and the pull necessary to cause slippage noted. In figure 6 are sketched the methods of bending the wires in this series. The wire in specimen 1 was bent in a 2-inch diameter circle at the end. The wire in specimen 2 was similar, except that there were two coils instead of one,

with a ½-inch pitch between them. Specimen 3 had a U-shaped bend on a 2-inch diameter, with the end of the wire bent in on a 1-inch diameter at the top of one leg of the U. The bend in specimen 4 was S-shaped, bent on a 2-inch diameter. Specimen 5 was spirally wound, with four coils ¾ inch in diameter and a pitch of ¾ inch.

The specimens were made from concrete designed to have a strength of 3,000 pounds per square inch. The cylinder strengths are given in table 10. Table 12 shows the results of these tests.

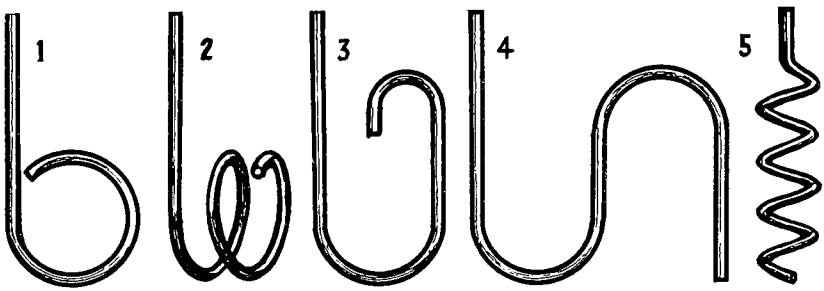

Figure 6.—Methods of bending wire in tests to determine the best means of anchoring ends of wire after coil is in place.

TABLE 12.—*Results of tests to determine a means of anchoring the wire at the end of a coil or loop.*

Specimens	Load for bond failure	Ultimate load	Deflection at ultimate load
Number	*Pounds*	*Pounds*	*Inches*
1	350	1,200	0.145
2	300	2,000	0.105
3	350	2,000	0.110
4	...	1,500	....
5	...	800	....

In specimen 4 the wire pulled out the side when the load was applied, making the determination for bond failure and the observation of deflection impossible. In specimen 5 the first coil of the spiral, which had a covering of only ½ inch, straightened out when a load of 800 pounds had been applied.

Conclusions

The method of anchorage in either specimens 2 or 3 is satisfactory, except that rather high deflection gauge readings were obtained, showing that there was some slippage in addition to the elastic strain in the wire.

Specimen 5 doubtless would have given good results had a greater depth of cover been used.

The two coils in specimen 2 developed a stress in the steel of 114,000 pounds per square inch, but with some slippage. Three coils would probably reduce the slippage to satisfactory limits.

Procedure

Series IV

In this last series a number of small beams were made for the purpose of determining whether high elastic-limit steel wire would give results comparable to those obtained with ordinary reinforcing bars when only half as much of the high elastic-limit wire was used.

The beams were 6x6x32 inches. The center of the steel was 4½ inches below the top of the beam in all specimens. One set of beams was made, using concrete designed for a strength of 3,000 pounds per square inch. Three more beams were made, using slightly stronger concrete.

Beam 1 contained three ⅜-inch deformed reinforcing bars, with hooked ends bent on a 2-inch diameter.

In beam 2 high elastic-limit wire was used. One piece of the wire was wound with four complete loops in a coil 30 inches in length. Another piece was wound in a coil of four loops, but only 16 inches in length. The wires were touching each other vertically and were 4 inches apart horizontally. Each loop was bent on a 4-inch diameter at the ends.

Beam 3 was reinforced with high elastic-limit wire, but with only half the steel area. The wire was wound in a coil 30 inches in length, with four complete loops.

The reinforcement in beam 4 consisted of three ½-inch deformed reinforcing bars. The ends were bent in a hook on a 2½-inch diameter.

Beam 5 was reinforced in a manner similar to that of beam 2, except that there were four strands on one side of the large coil and only three on the other. This gave a steel area equal to one-half that in beam 4.

Beam 6 also was reinforced in a manner similar to that of beam 2, except that two loops at each end of the large coil and one at each end of the small coil were bent up for shear reinforcement. The spacing between the bent-up loops was 3 inches. They were bent on approximately a 45-degree angle, and the ends were within an inch of the top of the beam.

The comparative steel areas in the beams are shown in table 13.

TABLE 13.—*A comparison of steel areas in the different beams.*

Beams	Reinforcement	Area of steel	Steel percentage
Number		*Square inches*	*Percent*
1	⅜-inch deformed bars	0.33	1.22
2	16 high elastic-limit wires	0.33	1.22
3	8 high elastic-limit wires	0.165	0.61
4	½-inch deformed bars	0.59	2.18
5	15 high elastic-limit wires	0.305	1.12
6	16 high elastic-limit wires, with 6 bent-up loops	0.33	1.22

One each of the beams was made from the 3,000-pound concrete. The cylinder strengths for this concrete at the time the beams were broken are shown in table 14.

TABLE 14.—*Cylinder strengths of concrete designed to have a strength of 3,000 pounds per square inch in beam tests.*

Cylinders	Total load	Strength per square inch	
Number	*Pounds*	*Pounds*	
1	25,220	3,567	
2	25,460	3,601	Average 3,590
3	25,480	3,604	

A second set of three beams reinforced in the same manner as beams 4, 5, and 6 were made, using the stronger concrete. The cylinder strengths for this concrete at the time of testing the beams are given in table 15.

TABLE 15.—*Cylinder strengths for the concrete used in the second set of beams, numbers 4a, 5a, and 6a.*

Cylinders	Total load	Strength per square inch	
Number	*Pounds*	*Pounds*	
1	31,090	4,397	
2	30,460	4,308	Average 4,335
3	30,400	4,300	

The beams were broken by a concentrated load at the center. The clear span was 26 inches. One end was embedded in plaster of Paris on a 2½-inch flat support. The other end rested on a 1-inch diameter support. The load was transmitted by a 1-inch diameter bearing.

The behavior of the beams under load is shown in tables 16 and 17.

In figure 7 are shown two of the beams. The shear failure in the top beam is typical of all beams except beam 3, shown on the bottom, with the vertical crack indicating tension failure.

In table 18 are recorded the calculated stresses in the concrete and the steel when the beams failed.

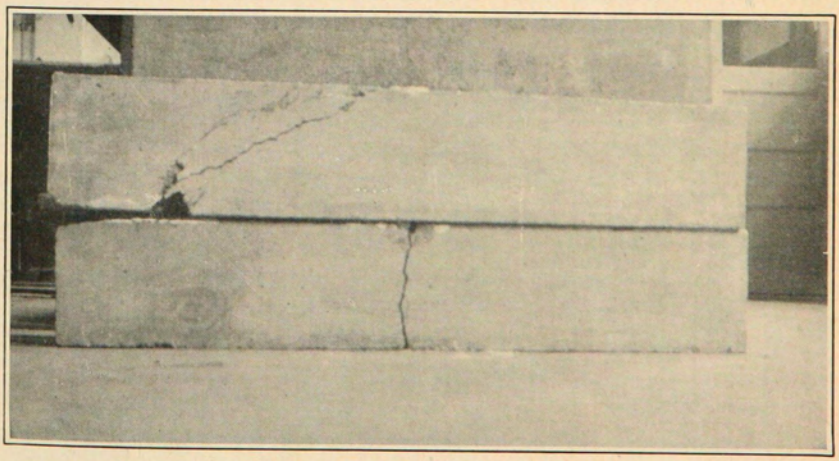

Figure 7.—Two of the beams of series IV.

TABLE 16.—*Deflections as load was applied to first set of beams.*

Beams	Load	Deflection	Remarks
Number	*Pounds*	*Inches*	
1	5,000	0.013	
	8,000	0.032	
	9,000	0.048	
	9,390	0.065	Crack appeared
	10,000	0.075	
	11,000	0.100	Failure
2	5,000	0.017	
	8,000	0.035	
	9,000	0.045	Crack appeared
	10,000	0.055	
	10,340	0.065	Failure
3	5,000	0.022	
	6,840	0.057	Crack appeared
	8,000	0.090	
	9,000	0.110	
	10,000	0.165	
	11,000	0.215	
	13,590		Failure
4	5,000	0.012	
	8,000	0.024	
	9,000	0.028	
	10,000	0.032	
	11,000	0.037	Crack appeared
	12,000	0.044	
	14,000	0.070	
	16,000		Failure
5	4,000	0.013	
	5,000	0.020	
	6,000	0.028	
	7,000	0.035	
	7,500	0.050	Crack appeared
	8,000	0.075	Failure
6	5,000	0.012	
	8,000	0.029	
	9,000	0.035	
	10,000	0.040	
	11,700	0.065	Crack appeared
	12,000	0.130	
	14,000	0.210	
	15,500		Failure

TABLE 17.—*Deflection in beams of slightly stronger concrete as load was applied.*

Beams	Load	Deflection	Remarks
Number	*Pounds*	*Inches*	
4a	5,000	0.010	
	8,000	0.023	
	9,000	0.027	
	10,000	0.031	
	12,000	0.047	
	13,000	0.060	Crack appeared
	14,000		Failure
5a	5,000	0.018	
	8,000	0.041	
	9,000	0.050	Crack appeared
	10,000	0.062	
	12,000	0.080	
	13,560	0.090	Failure
6a	5,000	0.019	
	8,000	0.045	Crack appeared
	9,000	0.060	
	10,000	0.090	
	12,000	0.130	
	15,000	0.200	
	15,210	0.270	Failure

TABLE 18.—*Stresses at failure for each beam.*

Beams	Stress in concrete per square inch	Stress in steel per square inch	Shearing stress per square inch	Bond stress per square inch
Number	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	3,490	55,300	234	396
2	3,280	52,300	220	324
3	5,500	132,800	279	411
4	4,250	45,900	353	449
5	2,600	42,900	169	285
6	4,900	78,300	329	388
4a	3,900	42,400	326	415
5a	4,400	72,700	286	483
6a	4,830	77,000	323	381

Conclusions

No beam failed due to lack of anchorage, regardless of the number of wires in a vertical tier.

Beam 3 failed at a greater load than beam 1, with a stress in the steel of more than twice as much; yet beam 3 had only half the steel area of beam 1.

Beams 4a and 5a failed at approximately the same load. Beam 5a had one-half the steel area of beam 4a.

Due to the extremely light load required to cause failure in beam 5 as compared to the other beams, it was not considered a fair test and was disregarded in drawing conclusions.

By a comparison of beams 1 and 3 and 4a and 5a, it is seen that one-half the steel area of high elastic-limit wire will give substantially the same beam strength as the full balanced percentage of ordinary reinforcing bars. The deflections were higher with the high elastic-limit steel but at working stresses were not high enough to be objectionable.

When equal steel area was used, the deflection was practically the same for both types of reinforcing. This shows that the looped anchorage compensated for the low bond resistance of the cold-drawn wire.

Bending up some of the loops increased the shearing resistance about 40 percent.

Apparently the variation in length of loop should be gradual, rather than the abrupt change from a 30-inch to a 16-inch loop, as in beams 2 and 5. This seems reasonable.

The absence of cracks throughout the length of beam 3, with the exception of the one at the center, indicates that bond failed completely and that the steel stress of 132,000 pounds per square inch was developed by anchorage alone.

Since bond is not necessary in this method of placing reinforcing steel, the steel could be given a protective coating of paint or other substance to prevent or retard corrosion where it is likely to occur.

Conclusion

As was stated in the introduction, the purpose of this study was not to arrive at definite and proven conclusions regarding the method of reinforcing concrete with loops of wire. Obviously, this could not be done in the scope of one short investigation, when there has been little or no previous research on the subject.

What conclusions it is possible to draw, however, are most gratifying. It is believed that further study will make possible a perfection of details, so that this method of reinforcing concrete will prove an advantageous one.

NOTES

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426	Oiled-Gravel Roads of Colorado
427	Insect and Mite Pests of the Peach in Colorado
428	Pyrethrum Plant Investigations in Colorado
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Colorado Experiment Station

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