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Bond of wires in prestressed concrete, December 1953

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BOND OF WIRES IN PRESTRESSED CONCRETE

by

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in cooperation with

Professors W. J. Eney and K. E. Knudsen

This work has been carried out in fulfillment of requirements for

C. E. 404 - Structural Research Course

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I. INTRODUCTION

1. Objectives

The bonding properties of wires in prestressed concrete has been extensively investigated abroad and to some extent in the United States. At Lehigh University during the spring and summer of 1952, a few tests were made by Mr. Samir El Khuri to determine the distribution of bond stress of wire 0.10 inches in diameter within concrete specimens after the release of prestress. The length of embedment required at each end of the concrete specimens to transfer all the stress from the wire to the concrete through bond was the primary purpose of his research project.* As his results were far from conclusive, a further investigation was necessary.

A successful extension of these bond studies necessitated the author acquire personal experience with both the application, waterproofing and use of SR-4 strain gages. An improvement in the gripping of the small diameter wire when stretching also had to be developed. With these problems solved, one beam was constructed using 0.100 inch diameter wires. The bond stress distribution at release of the prestress and the behavior of the beam during a flexure test to destruction were studied.

2. Test Program

The program was divided into 2 parts:

A. Experimental Techniques

(1) Determination of the comparative performance of

* Fritz Laboratory File 229--"Bond in Prestressed Concrete"
three adhesives used to apply SR-4 strain gages to steel and concrete surfaces, especially with regard to moisture resistance and ease of application.

(2) Comparison of ease of application and effectiveness of different products as a means of waterproofing SR-4 gages.

(3) Development of a practical method of gripping small diameter wires (0.10" Ø) for tensioning.

Investigations have previously been made on several adhesives and waterproofing compounds. After consulting with several persons experienced with this type of work and reviewing various papers on the subject, the number of adhesives and waterproofing compounds were narrowed down to a few for further tests and verification.

B. Bond Studies

Originally the program was planned to determine the length of embedment of both treated and untreated wires to fully transmit the prestressing force to the concrete by bond. Measurement of slip and the strain induced in small rectangular concrete sections was to be observed. However, this phase of the program was revised and this report is limited to the transfer of prestress by bond in a concrete beam later tested to destruction.
II. EXPERIMENTAL TECHNIQUES

1. ADHESIVES AND WATERPROOFING COMPOUNDS

Method of Analysis

SR-4 strain gages were applied on concrete cylinders using three different adhesives to investigate the effect of the moisture released from the concrete in the process of curing. Readings were taken from time to time with an SR-4 indicator and the change in strains were compared to a dummy gage placed on another cylinder from the same batch.

Waterproofing compounds were next investigated. SR-4 gages were applied on a flat steel surface and waterproofed with three different compounds and subsequently immersed in water. Strain readings were likewise taken. Since SR-4 gages were going to be used on 0.10 inch diameter wires embedded in concrete, an additional pilot test was also made with waterproofed gages on a wire later immersed in water.

Description of Tests

A. Tests on Adhesives--Two concrete cylinders were made from a single batch of concrete. Six SR-4 gages (two for each adhesive) were applied on one cylinder using the following adhesives:

(1) Duco Cement--Manufacturer: E. I. Dupont De Nemours and Company, Inc. This cement has been widely used in previous projects at Fritz Laboratory. It is the easiest to apply.

(2) Armstrong Epoxy Resin--Manufacturer: Armstrong Products Company, Warsaw, Indiana. This is
a relatively new product in the field. It has a limited pot life, from 30 minutes to 4 hours, depending on the activators used. It is very hard to apply because the gages have a tendency to curl up at the edges during application.

(3) Cycleweld--Manufacturer: Cycleweld Cement Products Plant, Trenton, Michigan. This is relatively easier to apply than Armstrong Epoxy Resin. It has a working life of about 20-30 minutes only. Curing takes about a day at room temperature.

Two dummy gages were applied to the second cylinder, one to act as a compensating gage and the other as a standard gage for drift correction. Initial readings were taken with a Baldwin SR-4 Strain Indicator. The specimen with the six active gages was subsequently immersed halfway in water to accelerate the passage of moisture from the interior of the concrete to the surface. None of the gages were immersed. Readings were taken on the gages at two day intervals over a period of two months. The apparent change in strain (or drift) of the six gages on cylinder #1 relative to the standard gage on cylinder #2 using the common dummy gage was considered to be the effect of moisture on the bonding adhesives.

On the basis of the results obtained on the first test, another test was made on a concrete block. Two gages were applied with Duco cement using Cycleweld as a primer and two gages using only Duco cement. Readings were taken in the same manner as the previous test.
B. Test on Waterproofing Compounds--Two separate tests were also conducted:

(1) Six gages were applied on a flat steel plate (Figure 2) by means of SR-4 cement and waterproofed by three different compounds:

(a) Gaco Neoprene--Manufacturer: Gates Engineering Company, Wilmington, Delaware. The process takes about six hours. A primer coat is first brushed on. Then a brushing cement is thoroughly mixed with an accelerator. This accelerated cement is brushed onto the gage six times waiting for the previous coat to dry before applying the next. The pot life of the compound ranges from 40 minutes to 24 hours depending on the accelerator used. The curing of the cement depends upon the amount of accelerator, which although not critical will affect the length of time it takes to apply this compound.

(b) Bostik Cement--Manufacturer: B. B. Chemical Company, Cambridge, Massachusetts. The process of applying this cement takes only a short time. The coating is applied to the gage by hand after previously cleaning the surface of application. The compound remains reasonably plastic even for quite a long period of time. It is extremely sticky when fresh and adheres very readily to the fingers.

(c) Petrosene Wax--This is Product 2300 of
Socony Vaccum. It is hard wax which liquidizes easily with the application of heat. The wax is poured over and around the gage and allowed to harden which takes only a few minutes. However, upon immersion in water, bubbles formed at the edges of the wax, giving the impression that wax does not stick too well to steel.

Two gages were placed on another flat steel plate utilized in the same manner as those in the adhesive test. Readings on the gages were taken over a period of one month and drifts were plotted accordingly.

(2) Three gages were applied on a tenth diameter (0.1" Ø) wire and then waterproofed in three different ways, to find out what means of waterproofing would be most suitable for the gages on the wires inside the beam to be poured:

(a) Gaco Neoprene--As previously described.
(b) Neobond--Manufacturer: Atlas Mineral Products Company, Mertztown, Pa. The process of application is almost identical to the Gaco Neoprene. It has previously been used successfully here at Fritz Laboratory to waterproof gages on both the pre-tensioned and post-tensioned concrete beams.*
(c) Brass tubing sealed at the ends with Bostik Cement--This is a "home made" way of waterproofing which developed through conversations with Prof. Eney and Prof. Knudsen. It is relatively much simpler and faster to apply. A brass tubing 1/4" Ø in diameter

* Fritz Lab File 223--"Prestressed Concrete Bridge Members".
is slipped into the wire to cover the entire length of the gage. The ends are crimped, then sealed with Bostik Cement.

The same procedure as in the steel plate was followed.

RESULTS AND CONCLUSIONS:

A. Adhesive Tests--The results obtained in the adhesive tests very clearly show that Duco cement is an excellent means of applying gages to concrete. Besides being very simple to apply, it has also proved to be quite resistant to moisture. The Armstrong Epoxy Resin did not produce very satisfactory results. The gages applied with this compound drifted considerably. Some difficulties have been encountered in its application, the gages having a tendency to curl up at the edges. Several other persons who have tried this adhesive also met with the same difficulties. Cycleweld, although it yielded better results than the Armstrong Epoxy Resin, is also just about as hard to apply. The results of the test are shown in Figure 3. No appreciable drifts in any of the gages were recorded up to about twenty days when the Armstrong gages showed some appreciable drift. The Cycleweld and Duco Cement both showed satisfactory results but Duco Cement is easier to apply. On the basis of these findings, Duco Cement is recommended for applying SR-4 gages on concrete.

B. Waterproofing Tests--Figures 4 and 5 indicate the drifts which followed a definite trend. The gages with petrosene wax was apparently affected by moisture in a
comparatively short time since it went out of range in eight days. Gaco Neoprene drifted the least.

From the behavior of the gages the following conclusions may be drawn:

(1) Product 2300 cannot be used on gages which are immersed in water. The wax does not adhere too well to the surface (especially on steel) so that water easily finds its way between the two materials. It may be very adaptable as a protection against moisture when carrying out field tests in the open air where the gages are not immersed in water but merely exposed to moisture. Its advantage lies in the ease and simplicity of application.

(2) Bostik Cement may be used on gages immersed in water when the readings are not taken over a long period of time. In tests lasting for about ten days, it affords satisfactory protection against the effect of water. However, it is not recommended for use in tests which extend for a considerable amount of time.

(3) Gaco Neoprene—This product gave the best results for the gage on the steel plate and was also effective in protecting the gage applied on a tenth diameter (0.1" Ø) wire. This method is complicated and takes a lot of time and patience. The amount of accelerator used in the mix affects the curing of the compound and in mixing small quantities consistent curing time is very hard to attain. Thorough stirring is also necessary while the cement is being brushed on. Bearing
in mind the amount of time required for its complete application, extensive use of it may not prove profitable.

(4) Neobond--No results were obtained in these tests because the gage grounded shortly after application. However, this product was used in the wires and strands on both prestressed concrete beams (Project 223) with very satisfactory results. The time element is again the main setback of this method. It takes even more time than the Gaco Neoprene and its accelerator being a heavy slurry, more thorough mixing is required. The amount of accelerator is all the more critical in small quantities so that utmost care and patience is required for its successful application.

(5) Brass tubing sealed with Bostik Cement--The gage waterproofed by this method held out as well as that waterproofed by Gaco Neoprene. Because of the short time it takes to apply, it was decided that this method would be used to waterproof the gages on the wires for the test beam.
FIG. 1. TEST ON ADHESIVES - SR-4 GAGES APPLIED ON CONCRETE CYLINDER HALFWAY IMMERSED IN WATER.

FIG. 2. WATERPROOFING TEST - SR-4 GAGES ON STEEL PLATE IMMERSED COMPLETELY IN WATER.
Figure 3. Adhesive test on concrete cylinders (SR-4 gages).
2. Method of Gripping Small Diameter Wires (0.10" Ø)

Several ways of gripping small diameter wires have been tried, among which are: The use of an Allen Set Screw with a bearing ball devised by Mr. Melville of the University of Virginia; threading the wire developed by Professors W. J. Eney and A. C. Loewer, Jr. here at Fritz Laboratory, a detailed description of which is found in Mr. El Khuri's report.* These methods, although feasible, were found successful only to a limited extent. They involved many difficulties and uncertainties and were time consuming.

Professors Eney and Knudsen initiated correspondence with the National Telephone Supply Co. regarding one of their products called Nicopress Sleeves used for terminating and splicing high strength wires and cables. A piece of the 0.10" Ø cold drawn wire was sent to the Company. They applied the sleeves and tested the specimen, reporting that the wire broke without any slip in the sleeves. One of their tools (No. 3 L Nicopress) was loaned to the project for a year and later purchased.

Description of Tests:

To verify the National Telephone Supply Co. tests, two pieces of the wire, each three feet in length were fitted with sleeves. The sleeves are made of a soft metal alloy and before pressing are tube-like in appearance. Pressing is done by simply crimping the sleeves with the tool. (Twelve

* Fritz Laboratory File 229--"Bond in Prestressed Concrete"
presses on each full-length sleeve, and six presses on each half-length sleeve.) These wires were tested in tension on the 60,000 lbs. Baldwin Hydraulic Testing Machine. Special washers were fabricated out of a 1/4 inch steel plate so that the sleeves pressed against these washers as the wire was stressed in tension. The wire was thus gripped solely by the sleeves.

Results:

The wire with the full length sleeves broke near the center at 2,125 lbs. (270,000 psi) with no slip in the sleeves. The wire with the half-length sleeves reached a load of 1,800 lbs. (230,000 psi) when one of the sleeves started to slip.

Since these wires for prestressing purposes are going to be stressed to about 1,100 lbs (140,000 psi), the Nico-press half-length sleeves were adequate and proved to be an excellent method of gripping the wires.
II. BOND STUDIES

METHOD OF ANALYSIS:

In order to determine the length of embedment, A-12, SR-4 gages were applied to each wire at various distances from the end of the beam. Readings on the SR-4 gages were taken before and after the release of prestress. A-11 gages were also applied on the surface of the concrete to verify the results obtained from the gages on the wires.

The beam was finally tested to failure to determine qualitatively the bonding properties of the wires under flexure. The beam was under-reinforced to insure yielding of the wires before the ultimate stress in the concrete is reached.

TESTING PROCEDURE:

1. Beam Dimensions-- The size of the test beam decided upon was 8" x 11" in cross section and 10 feet in length, reinforced by 10 - 0.1" Ø diameter wires in two layers. Each wire was initially stressed to 135,000 psi.

2. Forms-- To minimize on the costs, the side forms consisting of two 12" channels were used simultaneously as the jacking frame. This arrangement eliminated the possibility of placing Whittemore plugs or SR-4 gages on the side of the concrete at the level of the wires before the release of the prestress, which might have yielded some helpful data to confirm the results obtained from the gages in the wires.

3. SR-4 Gages-- Gages were applied to each wire at varying distances from the end, using Duco Cement and water-
proofed with brass tubing sealed with Bostik Cement, this method having yielded satisfactory results in the Immersion tests previously conducted. The beam was lifted from the bottom form five days after pouring and ten SR-4 gages were applied at the bottom of the beam. The gages were placed at definite distances from the end of the beam corresponding to the gages in the wires. However, the readings were very inconclusive and were, thus, discarded.

Location of SR-4 Strain Gages in the wires:

4. Prestressing the Wires—The wires were laid out in pairs and U-turned around a piece of a half rod at the end plate (Figure 1). To stress the wires, the device used by Mr. El Khuri consisting of a nut and bolt assembly was utilized. These prestressing units were inserted into the wires after which nicopress sleeves were pressed on the wires (Figures 2 and 3).

The modulus of elasticity of the wire was 30.6 x 10^6 psi. Since each wire had a gage, the wires were individually stressed until a strain of 4420 microinches was reached corresponding to a stress of 135,000 psi. (Figure 4). Each wire was, therefore, brought up to the required stress
very accurately. An effort was made to correlate the actual jack elongation to the theoretical elongation of the wire—
\( (4420 \times 10^{-6} \times 13.0 \times 12" = 0.70 \text{ in.}) \). Actual elongation of the jacks averaged 1-1/32 inches. This discrepancy may be attributed to losses due to friction in the prestressing units and shortening of the jacking frame itself.

5. Releasing the Prestress—Seven days after the beam was poured, the prestress was released by gradually loosening the jacks. Eight of the ten gages in the wires indicated reasonable readings. The length of embedment of the wires was determined by plotting the distance of the gages from the end of the beam against loss of prestress. In other words, if the gage registered about the same reading before and after release, the full bond-stress has been developed. (Figure 5).

6. Destruction Test—The beam was tested to failure twenty-one days after pouring. (Figure 6). In order to detect any bond failure causing slip in the wires, the protruding ends were whitewashed. Any scaling off would indicate some slip. Provision was made to measure beam deflections at the center line by means of a mirror scale and a taut wire. However, below fracture load, which was sudden, no deflection was discernable.
OBSERVATIONS & CONCLUSIONS:

1. The length of embedment was found to be around 130 to 150 wire diameters from the end of the beam. Figure 5 shows the predicted and observed variation of the bond stresses at the time of release. The predicted variation of the bond stresses was based on an equation of a third degree parabola developed by Dr. Ritter, Polytechnic Institute of Zurich. (See Appendix).

2. The waterproofing method used was satisfactory. It was observed that the gages, during the first two days, drifted a considerable amount from their original readings. This is possibly due to heat produced in the process of curing, heating up the wires, thereby affecting the gages.

3. The beam failed by crushing of the concrete after the yield point of the wires was reached. The ultimate load was 5,800 lbs. slightly below the predicted value of 6,200 lbs. There was no discernable deflection before cracking load. At ultimate load there was no immediate indication of slip. Some scaling off of the whitewash on the protruding wires was observed after the load was left on for some time. The wires, therefore, have very satisfactory bonding properties. The beam immediately after failure and a close up of the crack that developed at the center of the span are shown in Figures 7 and 8. There were two other cracks that formed but did not progress any longer than an inch long, vertically.
APPENDIX

A. Material Properties

1. Concrete-- The mix was designed according to ACI Specifications for 4500 psi at 28 days. The mix proportions was 1:2.12:1.74 by weight with a water-cement ratio of 0.49. Four batches of concrete were needed to provide for the required volume. Slump tests made on each batch were 3", 3½", 2½", and 2". One cylinder was taken from each batch.

Two cylinders were tested at 7 days and 21 days with the following results:

(a) 7 day concrete-- Modulus of Elasticity = 3.86 x 10^6
    (Figure 9) Ave. Ultimate Stress = 4300 psi

(b) 21 day concrete--Modulus of Elasticity = 4.43 x 10^6
    (Figure 10) Ave. Ultimate Stress = 6290 psi

2. Steel Wires-- The wires used in the test were cold drawn steel wires manufactured by J. A. Roebling's Sons Co. The Modulus of Elasticity was determined in a tension test, using two types of SR-4 gages (the A-12 and A-12-2). Both gages gave nearly identical results. The stress strain curve is shown in Figure 11. The Modulus of Elasticity found was 30.6 x 10^6 (Figure 12); the Ultimate Strength = 271,000 psi.
B. Analysis of Test Beam

1. Prestressing Force

(a) Initial wire stress = \( 4420 \times 10^{-6} \times 30.6 \times 10^6 = 135,000 \text{psi} \)

Initial Prestress = \( 135,000 \times 0.00785 \times 10 = 10,600 \text{ lbs.} \)

\[
\sigma_c = \frac{P + P_{ec}}{A - I}
\]

\[
= \frac{10600}{88} + \frac{(10600)(3)}{161}
\]

\[
= + 318 - 76
\]

(b) Initial Prestress

Stresses at centerline section:

\[
\begin{align*}
-70 & \quad + 76 \\
+70 & \quad - 76 \\
-70 & \quad + 318 \\
+248 & \quad - 218 \\
\end{align*}
\]

\( P_{DL} = 190 \text{ psi} \)

D.L. \quad P.S. \quad P.S. + D.L.

Loss due to Elastic Shortening of Concrete (at average level of wires):

\( \varepsilon_{str} = \Delta_{str} = \varepsilon_{str} = 0.0003 \times 30.6 \times 10^6 = 9180 \text{ psi} \)

Concrete Creep Loss - Assumed 2 times elastic loss = \( 3020 \text{ psi} \)

Total Loss = 12,200 psi

Initial Prestress = 135,000 - 1510 = 133,490 psi

(c) Final Prestress:

Shrinkage Loss \( \varepsilon_{sh} = \Delta_{sh} = 0.0003 \times 30.6 \times 10^6 = 9180 \text{ psi} \)

Concrete Creep Loss - Assumed 2 times elastic loss = \( 3020 \text{ psi} \)

Total Loss = 12,200 psi

Final Prestress = 133,490 - 12200 = 121290 psi

Final \( \varepsilon \) at average level of wires =

\[
\frac{121290}{30.6 \times 10^6} = 3950 \times 10^{-6}
\]
2. Predicted Curve of the Variation of Bond Stresses in the Wire From a formula by Dr. Ritter, Polytechnic Institute of Zurich:

\[ y = k \]

where \( k \) = final strain in the wire after full prestress is developed = \( 3950 \times 10^{-6} \)

\( x \) = distance from the end of the beam.

\( y \) = strain in the wire as the bond stress is being developed.

\( a \) = length of embedment when full prestress is developed.

Assuming that full prestress has developed at 13" from the end of the beam, the curves showing predicted and observed variation of bond stresses are found in Figure 6. The prestress was assumed to be fully developed 13" from the end of the beam, because the gage at that point hardly showed any loss of strain after release of prestress.

3. Ultimate Load--

Assumptions:

1. \( \varepsilon_c(\text{ult.}) = 0.30 \% \)

2. \( \varepsilon_s(\text{ult.}) = 1.08 \% \) as determined from stress-strain curve of the wire using 0.2 \% as permanent set.

3. The beam fails by crushing of the concrete when the wire stretches to 1.08 \% strain.

Stress of wire at 1.08 \% strain = 266,000 psi.
$C = T = (266,000)(0.0785)$

$= 20900 \text{ lbs.}$

$C = \frac{2}{3} f'c \ db$

$20,900 = \frac{2}{3} (6290)(8) \ d$

$d = 0.62 \text{ inches}$

$z = 8.5 - (0.62)(3/8) = 8.01''$

$M = Tz = (20900)(8.01) = 168,000 \text{ in. lbs.}$

$= 14000 \text{ ft. lbs.}$

$M = \frac{Pf}{4}$

$P (\text{ult.}) = \frac{(14000)(4)}{9} = 6200 \text{ lbs.}$
FIG. 1. END PLATE OF THE JACKING FRAME ON THE ANCHOR END.

FIG. 2. A NICOPRESS HALF-LENGTH SLEEVE BEFORE & AFTER PRESSING AND NUT & BOLT ASSEMBLY USED TO STRESS THE WIRES.
FIG. 3. THE SLEEVES BEING APPLIED ON THE WIR E S WITH THE NICOPRESS TOOL.

FIG. 4. STRESSING THE WIRES INDIVIDUALLY. 
Note waterproofed SR-4 gages with lead wires.
FIGURE 5. VARIATION OF BOND STRESS IN THE WIRES.
FIG. 6. ZERO READINGS BEING TAKEN DURING DESTRUCTION TEST.
FIG. 7. THE BEAM IMMEDIATELY AFTER FAILURE.
FIG. 8. A close up of the crack as it progressed to the top of the beam.
**Figure 9**

**Modulus of Elasticity**

**Cylinder at 7 Days (C-1)**

\[
E = \frac{S}{\varepsilon} = \frac{2120 - 21}{562 - 31} = 3.86 \times 10^6
\]
**Figure 10**

**Modulus of Elasticity**

Cylinder at 21 Days (C-8)

\[ E = \frac{S}{\varepsilon} = \frac{1980 - 71}{4.44} = 4.43 \times 10^6 \]

- - 1st Run

- - 2nd Run

- - 3rd Run

Stress in Lbs./Sq. In.

Strain in Microinches/In.
Figure 12: Modulus of Elasticity Test for 0.1096 Wire

\[
E = \frac{140250}{45\times10^{-8}} = 30.6 \times 10^6
\]
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C. A. Buenaventura
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