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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

RECORDING STRAINS AT THE END ZONE OF A PRESTRESSED CONCRETE I GIRDER WITHOUT END BLOCKS

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State of California
Department of Public Works
Division of Highways
Materials and Research Department

May 1963

Proj. W. O. R-68163

Mr. F. N. Hveem
Materials and Research Engineer
Materials and Research Department
Sacramento, California

Dear Sir:

Submitted for your consideration is a report of:

RECORDING STRAINS AT THE END ZONE

OF A

PRESTRESSED CONCRETE I GIRDER WITHOUT END BLOCKS

Instrumentation performed by . . . Structural Materials Section
Under direction of . . . . . E. F. Nordlin
Work supervised by . . . . . J. E. Barton and W. Chow
Report prepared by . . . . . A. Sequeira

Very truly yours,

E. F. Nordlin

E. F. Nordlin
Supervising Highway Engineer

AS:mw

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I. INTRODUCTION

This investigation consisted of instrumenting a prestressed concrete I girder 88'-5½" long, 54" high and without end blocks. The object of this test was to record the strain distribution along the end zone of the girder.

The instrumentation consisted of 37 strain gages, 5 temperature compensating (dummy) gages, and 16 thermocouples. Strain gages were installed on #4 and #6 reinforcing steel stirrups (vertical steel), #4 and #6 cross tie reinforcing steel bars, #4 longitudinal reinforcing steel bars and on steel wires of the pretensioned strands. The concrete girder was pretensioned with 24- ½" steel strands. Of the 24 steel strands, 10 were in the top section and were harped. The girder was steam cured for 15 hours. Steam was turned on at 6:00 P.M. and terminated at 8:00 A.M. the following morning. The strands were not released until three days after the pour. At this time a concrete test cylinder was stressed to 5500 pounds per square inch before failing.

This test was initiated by a letter dated March 22, 1963, from J. C. Nelle, plant manager of the Delta Prestress Concrete, Inc., asking if the Materials and Research Department would be interested in instrumenting the end zone of a prestressed concrete I girder to determine the strain distribution, particularly in the mild steel reinforcement. From the data secured, it may be possible to reduce the quantity of reinforcing steel in subsequent pretensioned prestressed concrete girders. The test instrumentation was conducted by the Structural Materials Section of the Materials and Research Department in conjunction with the Bridge Department and with the cooperation of Delta Prestress Concrete, Inc., Sacramento.

II. TEST PROCEDURE

The test procedure, after curing of the concrete girder, consisted of recording a complete set of (zero) strain measurements before the strands were released and a complete recording of strain measurements after the strands were released. A series of recordings were taken periodically for a period of 14 days. Thermocouples recorded the temperature from the time the concrete was poured to the time the strands were released. This latter period was approximately 70 hours.

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III. DISCUSSION

The following discussion describes the instrumentation installation, test data gathering and reduction of the test data.

The prestressing in the girder consisted of 24- ½" (1 x 7) steel strands (see Figure 1) with an ultimate strength of 41,300 pounds per strand. The cross sectional area of each strand was 0.160 square inches with an ultimate tensile stress of 260,000 pounds per square inch. All strands were pretensioned to 29,000 pounds or 181,000 pounds per square inch before the concrete was poured.

The first phase of the girder construction was to place two top steel strands and four bottom steel strands in the girder forms. The stirrups, premounted with strain gages in the laboratory, were then put in place along with the rest of the stirrups on that one girder side (see Figures 2A and 2B). The remaining strands were then put in place and tensioned (see Figure 3). The strain gages on the stirrups were placed 19" up from the soffit and were spaced and numbered according to Figure 4. Figure 5 shows the types of strain gaged reinforcing bars and the strain gage numbering system. Figure 6 shows complete steel frame in the end section of the girder.

The next phase of instrumentation was to install SR-4 gages on the wires of the bottom strands (see Figure 7). (Some tie bars have been temporarily removed in Figure 7 because of complexity of installing these gages.) Figure 8 shows the complete instrumented bottom section of girder. Also notice the cylinders which house the temperature compensating gages. Figure 9 shows the completed end section just prior to placing the other half of the steel forms.

During the curing period, temperature was recorded throughout the end section by means of 16 thermocouples and a 20 channel recorder. Temperature under tarp and air temperature were also recorded. Figure 4 indicates locations of thermocouples (TC) in the end zone of girder. TC-15 is temperature under tarp and TC-16 is the outside air temperature. The 16 thermocouple temperatures were recorded every hour from the time concrete was poured to the releasing of the strands 70 hours later. Table 1 shows these temperatures in tabulated form. Steam was on for approximately 15 hours. Figure 10 shows a graph of the average temperature in the girder, temperature under tarp, and temperature in air for the 70 hour period. Note the temperature under the tarp varies with air temperature. Also note that the curing temperature of girder fell short of the normal 140° F curing temperature by 15° F.

Two ten foot long longitudinal #4 reinforcing bars were strain gaged at 1, 3, 5, and 7 feet from one end. One of these reinforcing bars (LB) was placed along the bottom of the

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girder (see Figure 4). Figure 11 shows three curves of the strains along this reinforcing bar. The first curve was plotted with data obtained just after the strands were released. The other two were plotted with data obtained 4 and 9 days later. Later reading indicated that the strains in this reinforcing bar stabilized after 9 days. The strain gage data summary sheet (Table 2) shows strain changes up to ± 25 microinches per inch after that period. However, this was probably due to temperature changes between measurements. The other 10 foot reinforcing bar (LT) was placed along the top of the girder (see Figure 4). Figure 12 shows three curves of the strains along this reinforcing bar. Figure 11 shows the bottom of the girder progressively went into compression, reaching a peak strain of about 600 microinches/inch. The girder top, on the other hand, developed compressional strain to a peak of 250 microinches/inch and varied somewhat before stabilizing as shown by Figure 12. The top longitudinal bar strain also stabilized after 9 days.

Figure 13 is the distribution of stirrup strain at the level of the neutral axis (19" above the soffit) in the end zone of the girder. Note that the curves pass through zero strain at approximately thirteen inches from the end of the girder. Cracking was observed in the end zone where the girder was in tension. Note also that the strains also stabilized after 9 days.

Two of the four gages (B-1 through B-4) that were mounted on the steel wires of the pretensioned strands were destroyed when the strands were released. These gages were glued onto the wires of the strands at ten and twenty-two inches from the end. Due to strand slippage the two gages located at ten inches were destroyed when concrete wiped them off the wire. The other two gages are plotted with strains vs. time until the strains stabilized (see Figure 14).

Figure 15 shows a top view of the girder before pour. The narrow space between the reinforcing bars and the metal sides resulted in some strain gage damage due to the internal concrete vibrator used. A few of the gages were destroyed due to this process. This report recommends that external vibrators be used in future girders where strain gages are installed.

STRAIN GAGE INSTALLATION ON REINFORCING STEEL BARS

Baldwin A-8-1 strain gages were used on the reinforcing bars. These gages were used because of their availability in the laboratory stock and the lack of time to order more appropriate gage type. A small area of each bar gage location was machined and filed for placement of the strain gages. A minimum of steel was removed from each gage location so as not to materially reduce the bar area. The area was cleaned and degreased with acetone. The gages were glued down with Budd Type B-12 epoxy. Rubber bands were wrapped around the gage to keep it in place and then the glued units put under heat lamps for a period of two hours for curing. See Figure 16.

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Rubber bands were then removed and lead wires (Figure 17) were attached to the strain gage. Belden Type 8434 plastic insulated 4 conductor lead wire was used throughout.

The gage was now ready for waterproofing. MIBK primer solution was wiped on the plastic insulation so the waterproofing epoxy would adhere to it. The waterproofing epoxy was a two part epoxy-Thiokol mixture. It consists of two separately bulk packaged mixtures. One part by weight of Mixture #1 was mixed with two parts by weight of Mixture #2. The mixture in its uncured stage is like a heavy grease paste and does not sag. It cures to a solid elastic material. The uncured epoxy was applied to the gage area and the lead wires. The epoxy was only put halfway around the bar. It was then put under heat lamps and allowed to cure. A thin coat of Herecrol (RC-9) Synthetic Rubber Coating was brushed on the cured epoxy and up on the plastic insulation to complete the waterproofing. See Figure 18. Since time was limited, the reinforcing steel bars were put in water for only 16 hours in order to check the waterproofing. The reinforcing bars were ready for installation after the waterproofing tests.

Baldwin FAN-25-12, S6-L strain gages were used on the wires of the pretensioned strands. This type is a long narrow gage that fits best on the strands. The active gage area is ¼" long and only 0.025 inches wide. Eastman 910 contact cement was used on this gage because of the limitation of curing time. The Eastman 910 contact cement sets up upon contact pressure and the strain gage was ready for wire hookup and waterproofing immediately. Waterproofing was accomplished in the same manner as on the reinforcing bar gages.

Temperature compensating (dummy) gages were installed at various locations in the girder to compensate for any temperature changes. The dummy gage consisted of an SR-4 gage of the appropriate type glued to a steel bar 3" x ½" diameter. See Figure 19. The steel bar was then waterproofed and put in a cylinder 6" x 1" diameter and the ends were sealed off with waterproofing epoxy. Enough space was left inside the cylinder between the steel bar and waterproofing so that the steel bar could expand and contract without restraint due to changes in temperature.

A Baldwin type M strain indicator was used to make all strain measurements.

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PRESTRESS GIRDER

Temperature Recording in Prestress Concrete I Girder

DATE	TIME	TC-1	TC-2	TC-3	TC-4	TC-5	TC-6	TC-7	TC-8	TC-9	TC-11	TC-12	TC-14	TC-15	TC-16
4-12	1330	70	71	71	70	70	69	69	72	72	68	70	71	68	76
	1430	72	72	73	73	71	70	70	72	72	69	72	70	90	80
	1530	73	73	72	74	72	72	72	74	74	72	73	70	93	80
	1630	75	75	74	75	72	76	76	75	75	76	75	72	90	79
	1730	80	81	80	78	76	80	80	85	84	83	78	82	95	80
	1830	90	90	90	86	86	88	91	95	94	90	86	94	96	70
	1930	98	98	99	93	93	96	100	102	102	97	94	102	102	70
	2030	110	109	110	104	103	108	112	110	111	107	106	114	106	66
	2130	119	117	118	114	112	117	120	115	116	114	115	121	110	63
	2230	122	120	122	120	118	121	124	118	119	116	120	124	112	66
	2330	124	122	124	122	120	122	125	118	121	117	121	126	113	67
	2430	126	124	125	122	121	122	126	120	123	117	112	126	112	66
4-13	0130	127	125	126	124	122	123	128	120	124	118	124	128	112	61
	0230	127	126	127	124	122	123	128	120	124	117	124	128	110	63
	0330	127	126	127	124	121	122	128	119	124	116	124	126	108	60
	0430	126	126	127	124	121	122	128	119	124	115	124	126	106	62
	0530	126	126	127	124	120	120	127	118	124	114	123	125	105	64
	0630	125	124	125	122	119	119	126	115	122	112	122	123	104	78
	0730	123	122	123	120	117	118	124	113	120	112	120	121	112	79
	0830	122	121	122	119	115	118	124	112	120	113	119	119	117	82
	0930	122	120	122	118	114	120	124	114	120	117	118	118	121	74
	1030	122	119	120	116	112	122	123	112	118	118	118	117	122	82
	1130	121	118	120	116	112	122	123	110	117	118	117	115	117	70
	1230	121	118	119	117	110	122	123	109	116	116	116	114	112	69
	1330	119	116	117	115	109	120	121	106	114	112	113	112	102	66
	1430	117	112	115	110	107	116	118	102	110	110	111	110	104	74
	1530	114	110	110	109	105	114	116	99	108	107	108	107	100	74
	1630	112	108	110	108	103	112	114	98	107	104	107	106	97	65
	1730	110	106	108	106	101	110	111	96	105	102	104	104	96	64
	1830	108	104	106	104	100	107	108	94	102	100	102	101	92	70
	1930	105	102	104	100	98	104	106	92	100	97	100	100	91	64
	2030	103	100	102	100	96	102	104	90	99	95	99	98	90	63
	2130	100	98	100	98	95	100	102	89	97	93	97	96	87	66
	2230	98	96	98	96	93	97	99	87	95	90	96	95	84	67
	2330	95	94	96	94	91	94	96	86	93	88	94	93	83	68
	2430	94	92	94	93	90	92	95	84	91	86	92	91	82	67
4-14	0130	91	90	92	91	88	90	92	83	89	86	90	89	79	69
	0230	89	88	90	89	86	88	90	81	87	82	88	88	76	67
	0330	87	86	88	88	85	86	88	79	85	80	87	86	76	62
	0430	85	85	87	86	84	84	86	78	84	79	85	84	75	63
	0530	84	84	86	85	83	83	85	77	82	78	84	83	76	59
	0630	82	82	84	81	81	81	84	76	80	76	83	82	74	58
	0730	80	81	82	82	80	80	82	76	80	76	81	80	76	?
	0830	79	80	82	81	79	79	80	73	78	76	79	79	90	?
	0930	79	79	80	80	78	80	80	73	78	78	79	78	92	67
	1030	79	78	80	79	76	82	82	74	77	80	80	77	94	72
	1130	80	78	80	78	76	83	82	74	77	80	79	76	80	66
	1230	79	78	80	78	76	83	82	74	76	78	78	76	62	58
	1330	76	76	76	76	74	73	75	70	71	73	74	73	63	57
	1430	74	74	74	74	73	71	73	68	70	72	73	69	63	59
	1530	72	72	72	72	71	69	71	68	69	70	71	70	64	59
	1630	70	70	70	70	70	68	70	67	68	69	70	69	62	?
	1730	70	70	70	70	70	67	69	66	67	67	68	68	59	?
	1830	68	68	68	69	68	65	67	64	66	65	67	66	60	?
	1930	67	67	68	68	67	64	66	64	65	64	66	66	60	?
	2030	65	65	66	66	66	63	64	63	64	63	64	64	59	56
	2130	64	64	64	64	64	62	64	63	64	62	64	64	58	56
	2230	64	64	64	64	64	62	63	62	62	62	64	63	57	55
	2330	62	62	62	62	62	59	61	60	61	60	62	62	57	?
	2430	62	62	62	62	62	59	60	60	61	59	62	62	56	?
4-15	0130	60	60	60	60	60	58	59	59	59	58	60	60	54	?
	0230	59	60	60	60	60	56	58	58	58	57	59	60	53	?
	0330	58	59	59	59	59	55	56	56	56	56	58	58	50	?
	0430	56	57	57	57	57	53	55	56	56	54	57	58	52	?
	0530	55	56	56	56	56	52	54	54	54	53	56	57	52	?
	0630	54	56	56	56	56	53	54	54	54	53	55	56	54	?
	0730	54	56	56	56	56	54	54	54	54	54	55	55	55	?
	0830	56	56	56	56	56	55	55	55	55	56	56	56	56	?
	0930	56	56	56	56	56	56	56	56	56	57	56	56	56	58
	1030	58	58	58	58	58	58	58	58	58	60	58	57	62	58

NOTE: TC-10 and TC-13 not recorded.

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Table 2

STRAIN GAGE DATA

DATE	4-15	4-15	4-15	4-16	4-17	4-17	4-18	4-19	4-22	4-23	4-24	4-29
TIME HRS.**	0	2.5	3.25	20.5	45.0	50.5	69.0	93.5	165.5	141.0	165.0	285.0
TEMP. AVE.*	58°	58°	58°	55°	55°	64°	54°	56°	56°	51°	55°	59°
Gage No.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.	Strain u/in.
S-1	0	-20	-15	+30	-5	-50	-10	0	0	+25	-20	-35
S-2	+115	+110	+140	+230	+185	+190	+230	+270	+330	+300	+315	+315
S-3	-	-	-	-	-	-	-	-	-	-	-	-
S-4	-30	-55	-45	-25	-	-	-	-	-	-	-	-
S-5	+180	+200	-238	-200	-	-	-	-	-	-	-	-
S-6	+52	+40	+78	+145	+100	+50	+190	+105	+110	+140	+90	+80
S-7	-20	-20	-15	-20	-	-	-	-	-	-	-	-
S-8	+100	+90	+133	+200	+160	+120	+165	+175	+195	+190	+180	+165
S-9	-	-	-	-	-	-	-	-	-	-	-	-
S-10	-5	-40	-30	-20	+10	-60	-10	-10	-20	-10	-45	-20
S-11	-10	-45	-35	-25	-35	-103	-45	-55	-25	-45	-75	-75
S-12	-15	-35	-30	-20	-20	-88	-58	-48	-63	-73	-73	-88
S-13	-15	-43	-42	-10	-60	-90	-60	-30	-70	-30	-80	-70
C 1	+10	+5	+20	+30	-5	+10	-10	+15	+10	+25	+5	+5
C 2	+35	+25	+45	+85	+85	+145	+175	+195	+205	+225	+195	+185
C 3	+50	+50	+55	+75	+40	+57	+30	+65	+55	+70	+45	+40
C 4	+7	+5	+20	+50	+60	+5	+25	+55	+85	+85	+55	+40
C 5	+50	+50	+65	+95	+40	+55	+40	+60	+20	+20	0	+10
K 1	-10	-16	-15	+15	-20	-25	-25	-30	-50	+5	-20	-20
K 2	0	-10	+5	+10	0	-30	-10	-40	-20	-10	0	-15
K 3	+5	-5	-5	+20	-20	-30	-45	-20	-30	+10	-20	-25
K 4	+15	0	+5	+55	+5	-15	-5	-5	-25	0	-10	-5
K 5	+45	+40	+55	+50	+55	+30	+30	+30	+25	+35	+25	+30
K 6	+35	+25	+35	+60	+25	+20	+10	+20	+20	+5	+20	+15
K 7	+22	+20	+25	+30	+20	-5	0	+10	-10	-15	+10	+10
K 8	+50	+35	+50	+40	+45	+10	0	+15	+15	+10	+5	+40
L B 1	-320	-340	-340	-300	-420	-399	-410	-430	-430	-410	-295	-385
L B 2	-375	-395	-390	-385	-465	-440	-470	-450	-500	-465	-555	-560
L B 3	-395	-413	-420	-420	-500	-470	-510	-485	-515	-520	-595	-615
L B 4	-238	-230	-275	-235	-315	-300	-320	-320	-300	-305	-360	-370
L T 5	-163	-185	-135	-90	-155	-195	-155	-115	-125	-135	-195	-185
L T 6	-168	-190	-175	-120	-140	-180	-160	-150	-140	-170	-215	-220
L T 7	-210	-220	-210	-170	-175	-220	-220	-180	-170	-185	-245	-270
L T 8	-232	-250	-235	-165	-175	-230	-210	-180	-180	-180	-225	-250
B 1	-	-	-	-	-	-	-	-	-	-	-	-
B 2	-1310	-1410	-1440	-1700	-1815	-1865	-1900	-1980	-2125	-2110	-2150	-2170
B 3	-	-	-	-	-	-	-	-	-	-	-	-
B 4	-1085	-1140	-1165	-1300	-1365	-1410	-1390	-1395	-1625	-1635	-1615	-1615

NOTES: + Indicates tension strain, - indicates compression strain.

* Average temperature of girder.

** Zero time just prior to strand releasure.

- - - Indicates no data taken.

All strain data with zero reference to just prior to strand releasure.

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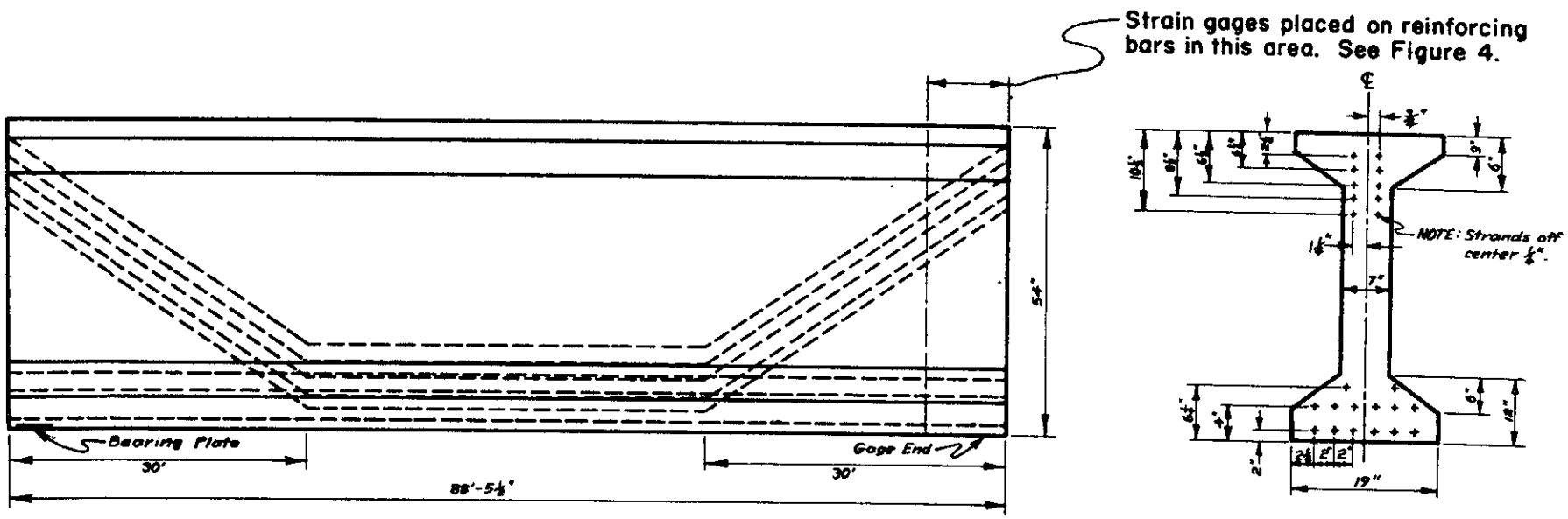
LOCATION OF PRETENSIONED STRANDS IN GIRDER



+ 7 WIRE PRETENSIONED STRAND
NO SCALE

Figure 1

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Figure 2A

Strain gaged stirrups and 6 pretensioned strands.

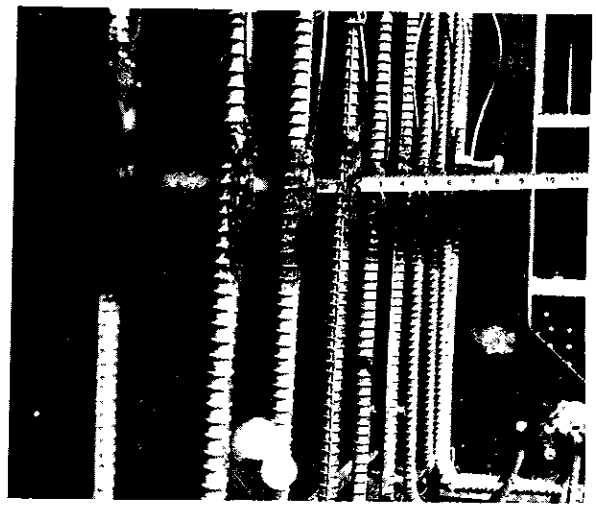

Figure 2B

Shows relative size of bar and waterproofing of gage.

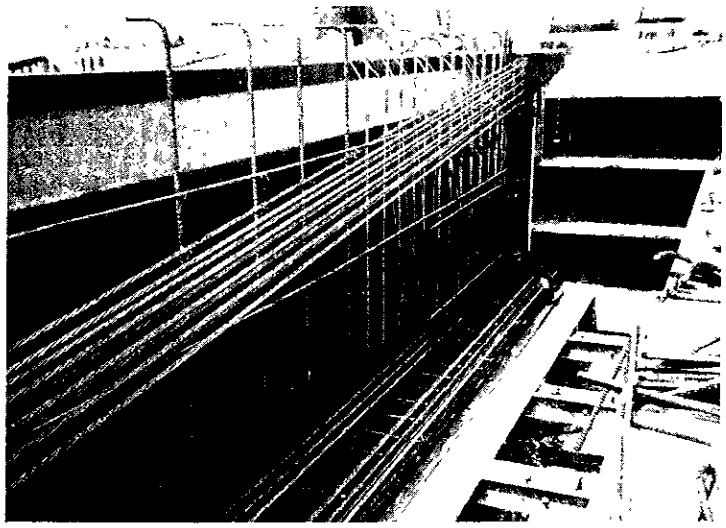

Figure 3

Shows pretensioned strands and stirrups on one side.

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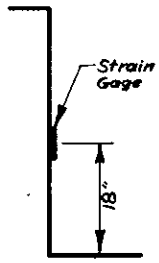
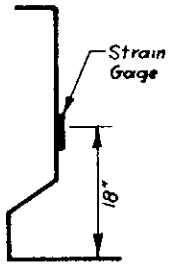
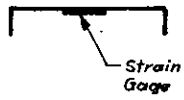
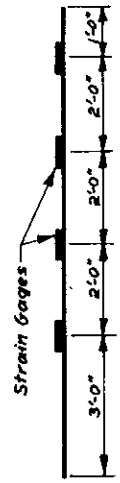
TYPES OF STRAIN GAGED REINFORCING BARS AND NUMBERING SYSTEM

STRAIN GAGE Nos.	SIZE	GAGE LOCATION
S-1 Thru S-8, S-12, S-13	#6	
S-9, S-10, S-11	#4	

STRAIN GAGE Nos.	SIZE	GAGE LOCATION
C-1 Thru C-5	#6	
K-1 Thru K-8	#4	
LB-1 Thru LB-4 LT-5 Thru LT-8	#4	

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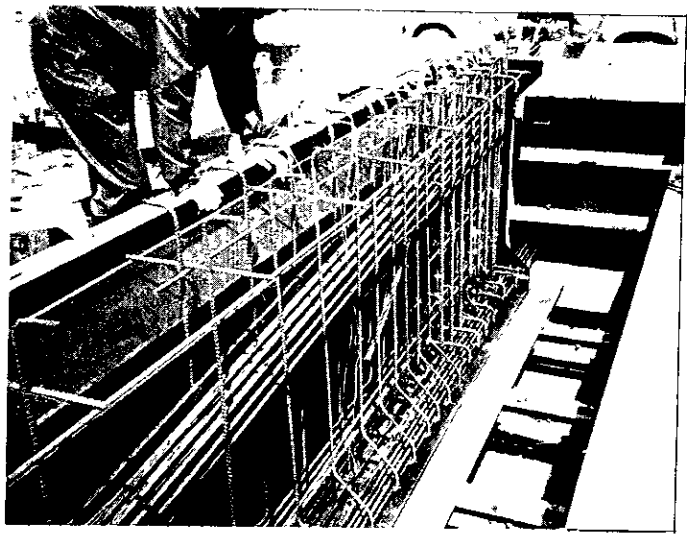

Figure 6

View of girder with all reinforcing steel in place.

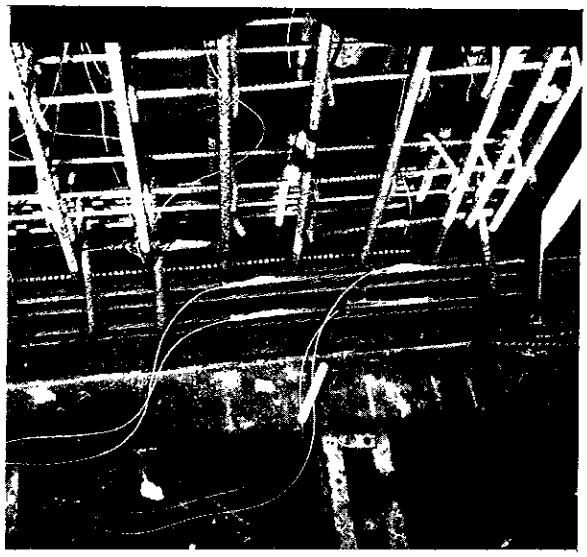

Figure 7

View of bottom section of girder showing strain-gaged strands.

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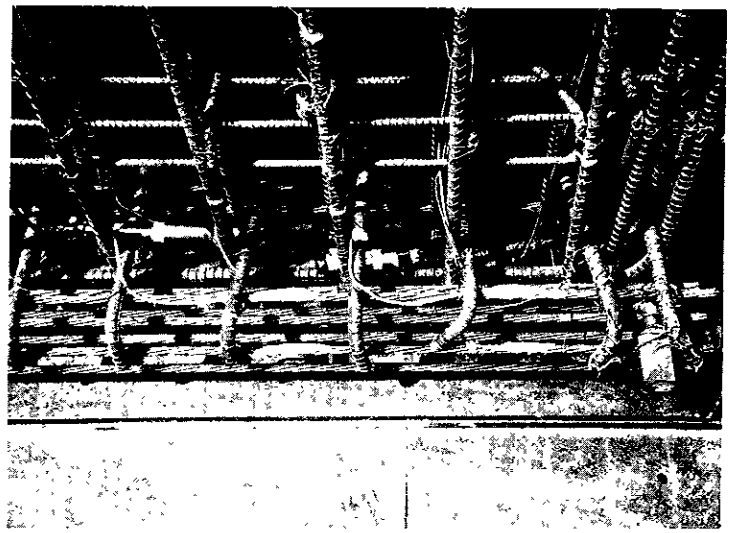

Figure 8

Complete instrumented bottom section of girder.

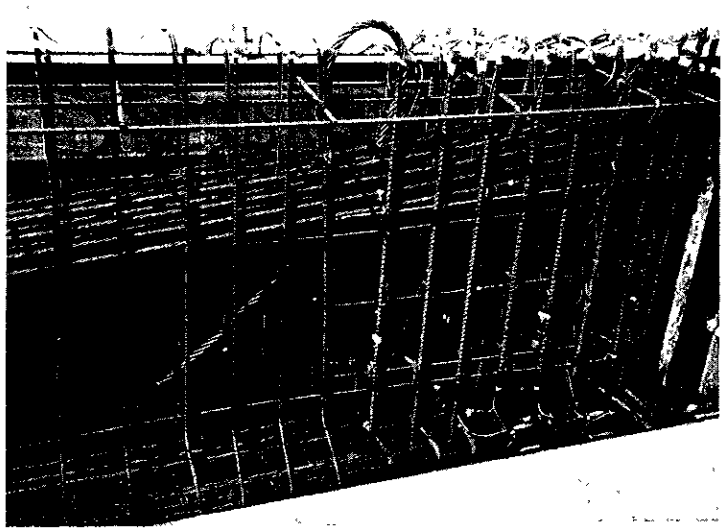

Figure 9

Completed instrumented section of girder.

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AVERAGE TEMPERATURE INSIDE GIRDER AND AIR TEMPERATURE UNDER TARP DURING CURE PERIOD

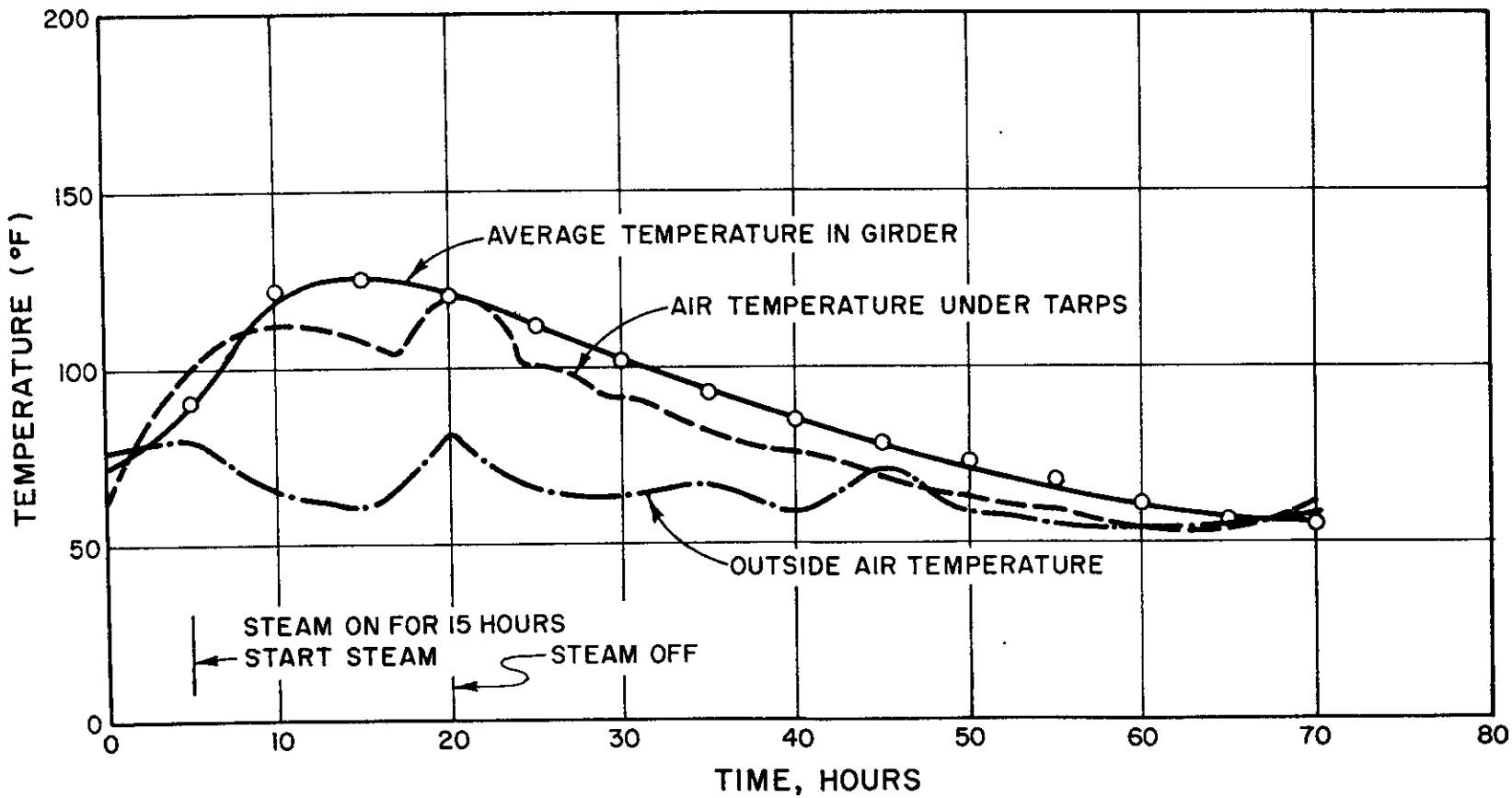

Figure 10

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DISTRIBUTION OF LONGITUDINAL STRAIN ON A #4 BAR (LB) LOCATED AT THE CENTER OF THE BOTTOM OF THE GIRDER

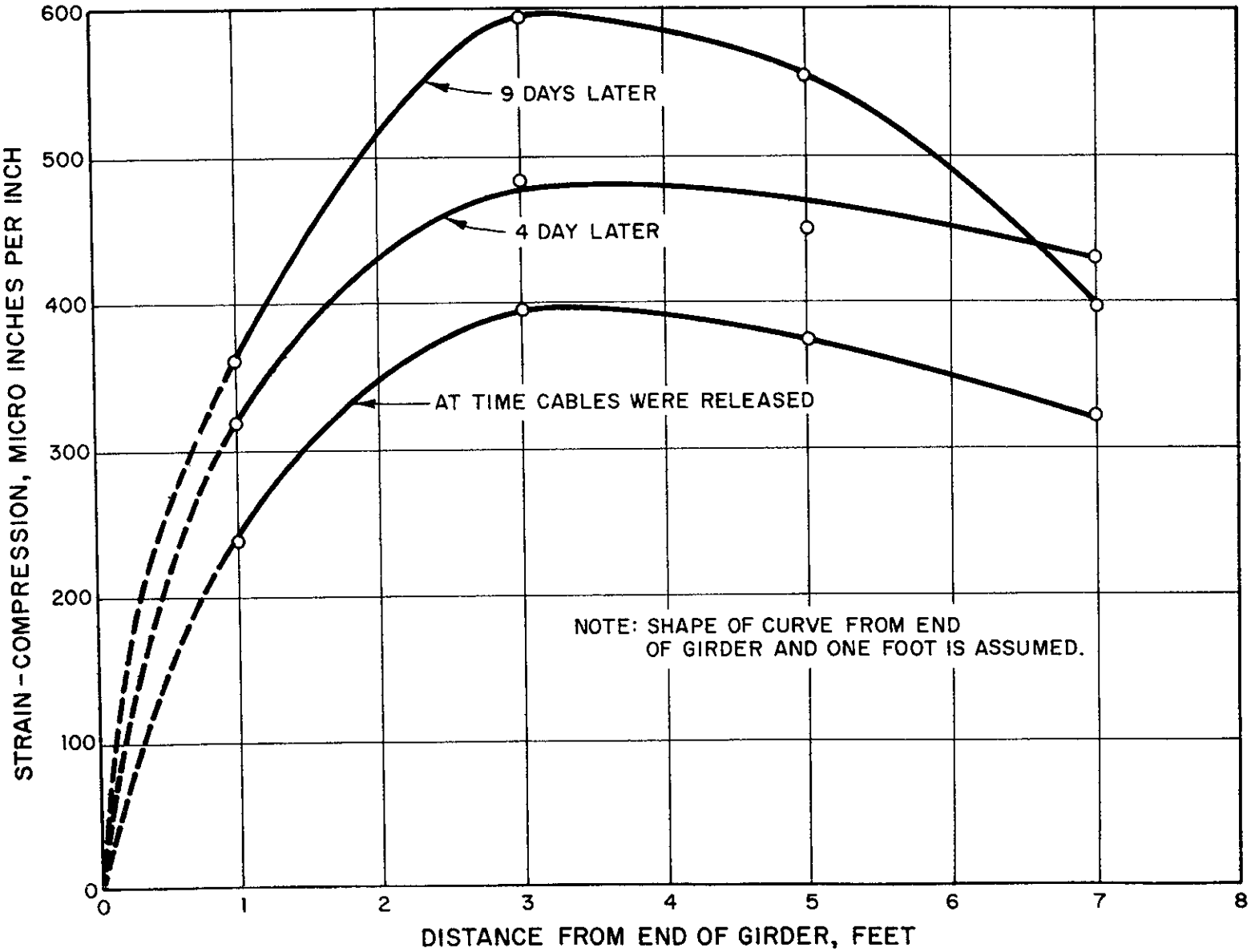

Figure 11

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DISTRIBUTION OF LONGITUDINAL STRAIN ON A #4 BAR (LT) LOCATED AT THE CENTER OF THE TOP OF THE GIRDER

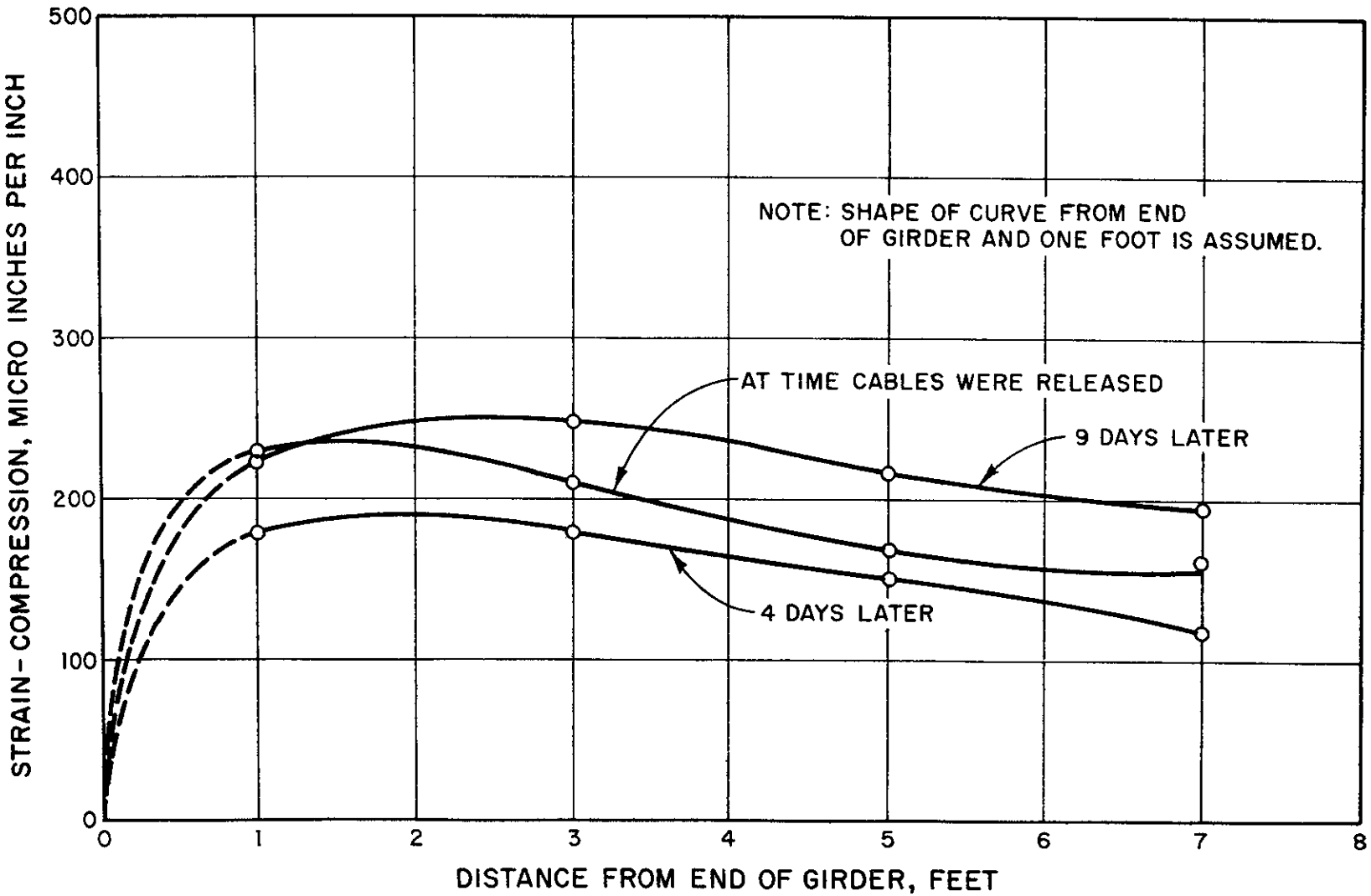

Figure 12

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DISTRIBUTION OF VERTICAL STIRRUP STRAIN AT THE LEVEL OF THE CENTRAL AXIS (19" ABOVE THE SOFFIT) IN THE END ZONE OF THE GIRDER

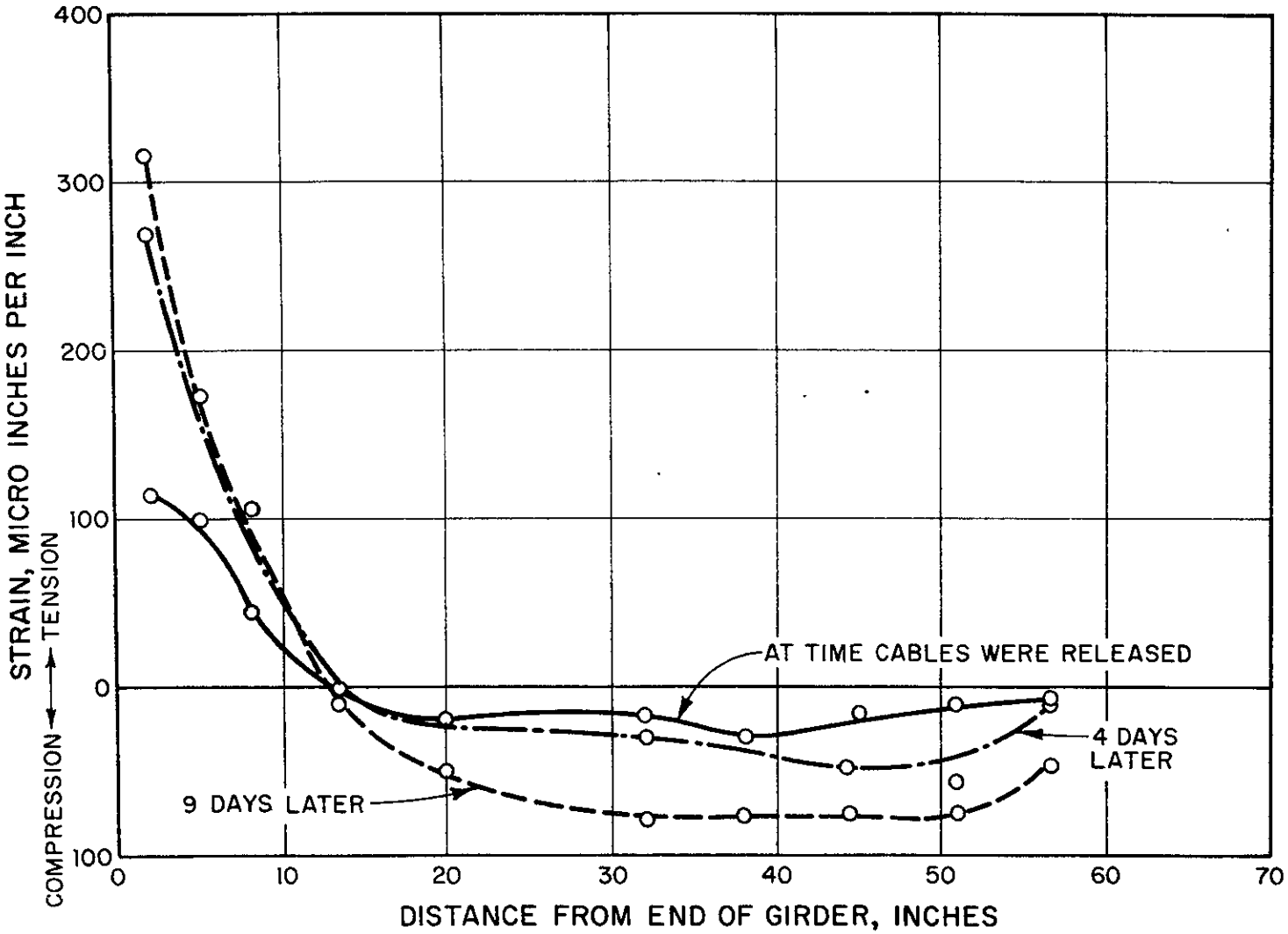

Figure 13

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STRAIN ON STRANDS AT A POINT 22 INCHES FROM THE END OF THE GIRDER

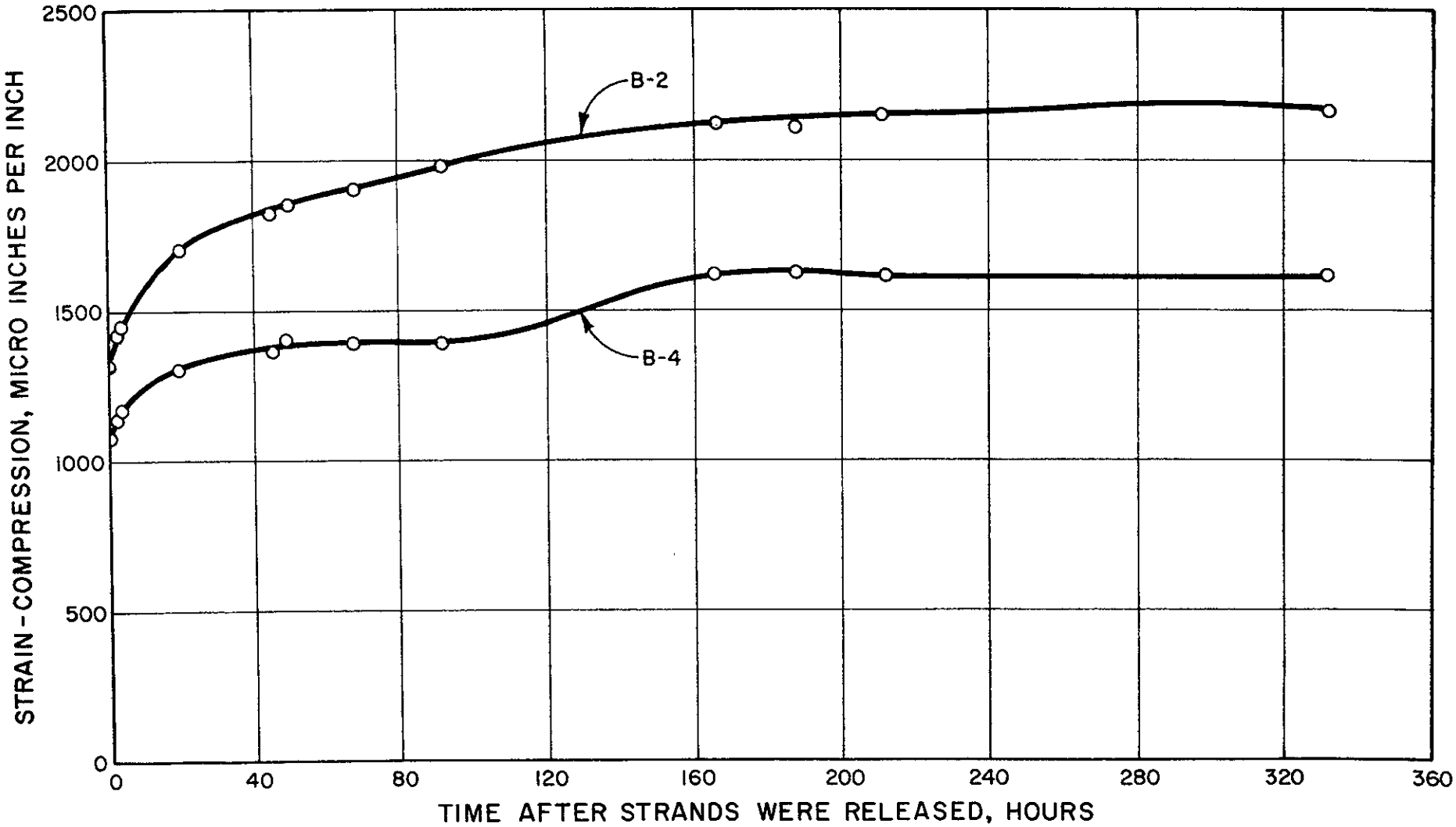

Figure 14

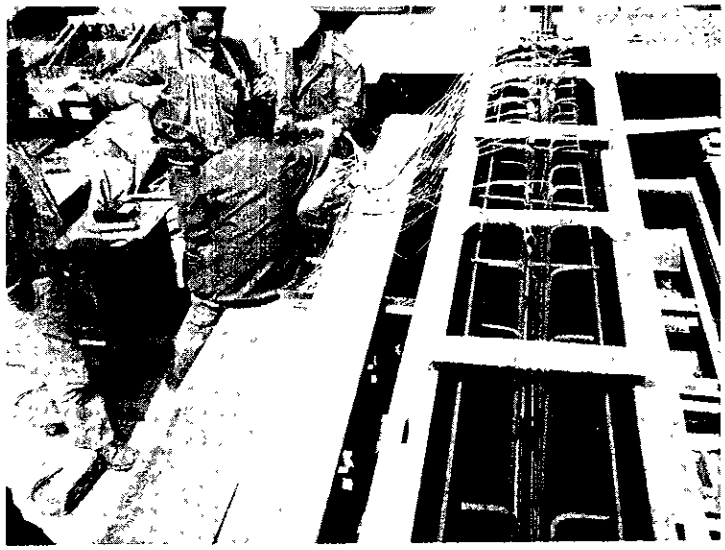

Figure 15

Top view of girder shows
strain gage lead wires.

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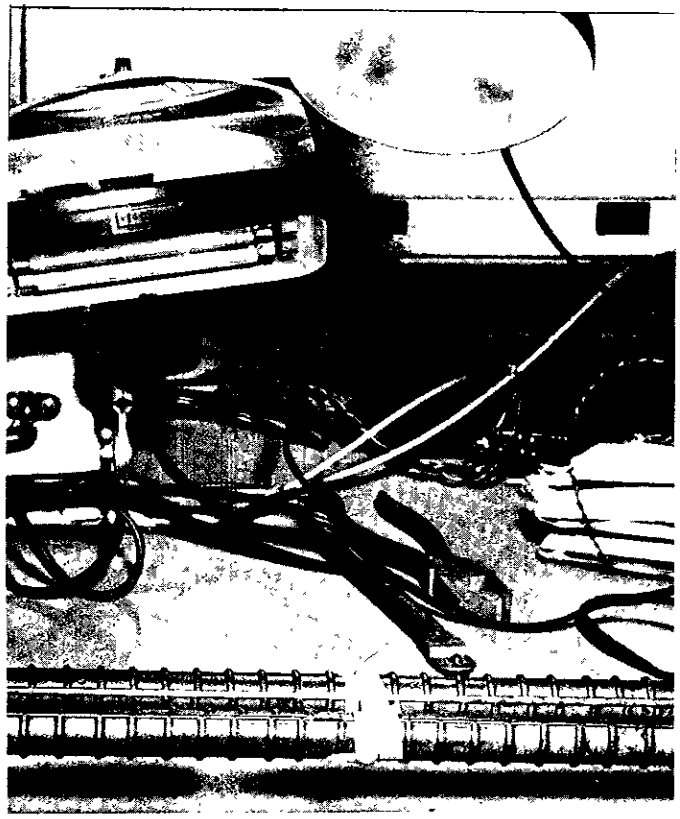

Figure 16

Heat curing of strain gage on reinforcing bar.

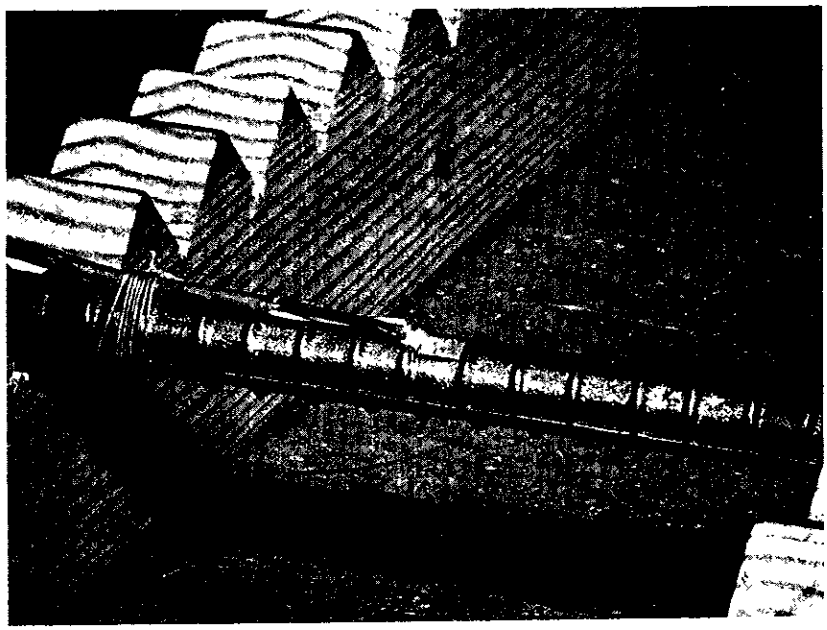

Figure 17

Completed strain gaged reinforcing bar before waterproofing.

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Figure 18

Curing of waterproofing.

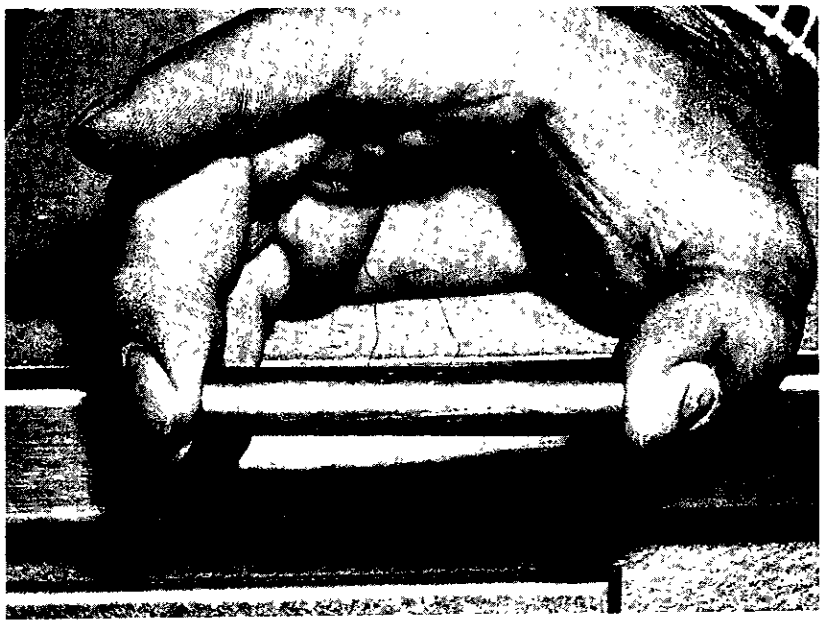

Figure 19

Temperature compensating gage glued to a 3" x ½" diameter rod.

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