Final Report
Project HR-62

INVESTIGATION OF THE LOSS OF PRESTRESS IN PRESTRESSED CONCRETE BEAMS DUE TO STEAM CURING

Research Department
Iowa State Highway Commission

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Investigation Of Loss Of Prestress In Prestressed Concrete Beams Due To Steam Curing

INTRODUCTION

Mass production of prestressed concrete beams is facilitated by the accelerated curing of the concrete. The method most commonly used for this purpose is steam curing at atmospheric pressure. This requires concrete temperatures as high as 150°F. during the curing period.

Prestressing facilities in Iowa are located out of doors. This means that during the winter season the forms are set and the steel cables are stressed at temperatures as low as 0°F. The thermal expansion of the prestressing cables should result in a reduction of the stress which was placed in them at the lower temperature. If the stress is reduced in the cables, then the amount of prestress ultimately transferred to the concrete may be less than the amount for which the beam was designed.

Research project HR-62 was undertaken to measure and explain the difference between the initial stress placed in the cables and the actual stress which is eventually transferred to the concrete. The project was assigned to the Materials Department Laboratory under the general supervision of the Testing Engineer, Mr. James W. Johnson.

A small stress bed complete with steam curing facilities was set up in the laboratory, and prestressed concrete beams were fabricated under closely controlled conditions. Measurements were made to determine the initial stress in the steel and the final stress in the concrete. The results of these tests indicate that there is a general loss of prestressing force in excess of that caused by elastic shortening of the concrete. The exact amount of the loss and the identification of the factors involved could not be determined from this limited investigation.

SCOPE OF PROJECT

If for any reason the full stress initially developed in the steel cables is not transferred to the concrete, this fact should be evident from measurement of the stress in the concrete. This was the basis for the procedure used in the investigation.

It was assumed that the measurable difference in the stress can be attributed to (1) the elastic shortening of the concrete, (2) the reduction of stress in the steel due to thermally caused stress relaxation during the steam curing period, and (3) other losses which are small in comparison to the first two.

EQUIPMENT

A prestressing bed, capable of stressing four 7/16 inch steel cables for a ten foot beam, was constructed in the laboratory building, (Fig. A).

The elevated curing temperature was provided by admitting steam within the hood which encased the beam.

A continuous record of the internal beam temperature was obtained with a recording thermometer, (Fig. B).

The pretensioning load on the cables was provided with a hydraulic jack. After the proper tension was applied to the cables, the tension was maintained by securing the end plates of the prestressing bed with four large threaded rods, (Fig. C).

Calibrated load cells and electrical strain indicating devices determined the load applied to the cables, (Fig. B).

Strains in the cured concrete beam, induced by the prestressing force, were measured with Whitmore mechanical strain gauges, (Fig. D).

The concrete was mixed in a Lancaster counter-current batch-type mixer.

MATERIALS

All materials used for making concrete met the specifications of the Iowa State Highway Commission. The same materials and the same proportions were used throughout this investigation.

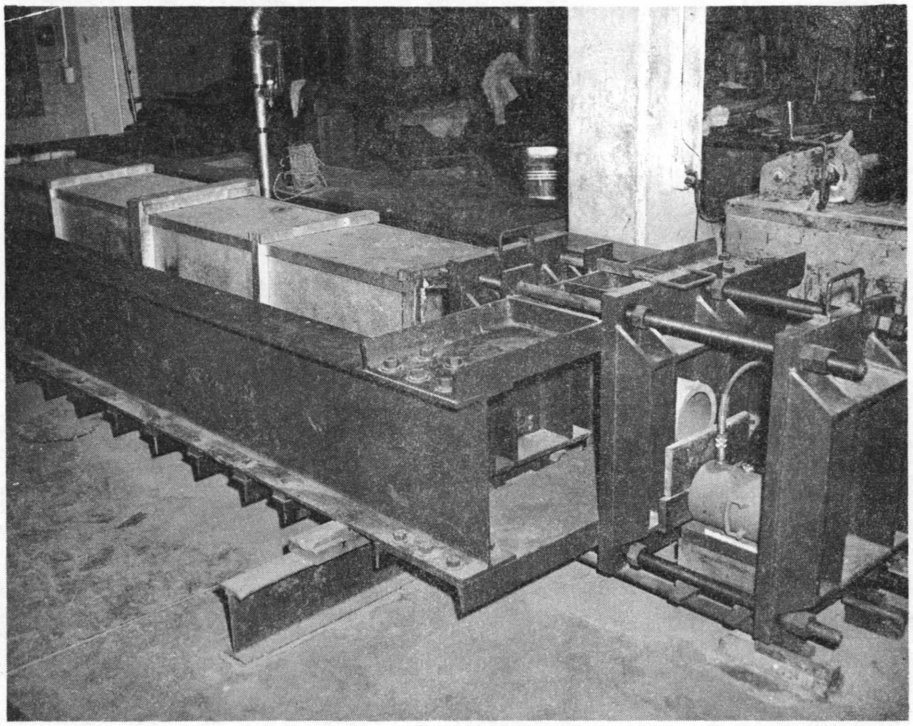

Fig. A Laboratory Prestressing Bed

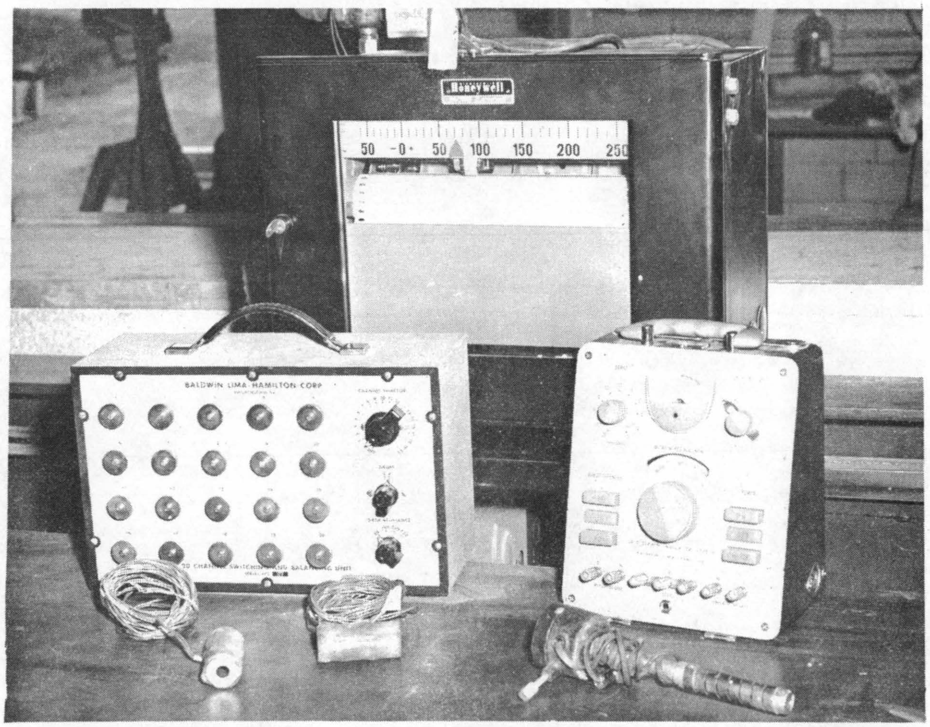

Fig. B Electrical Strain Indicating Equipment, recording thermometer and load cells

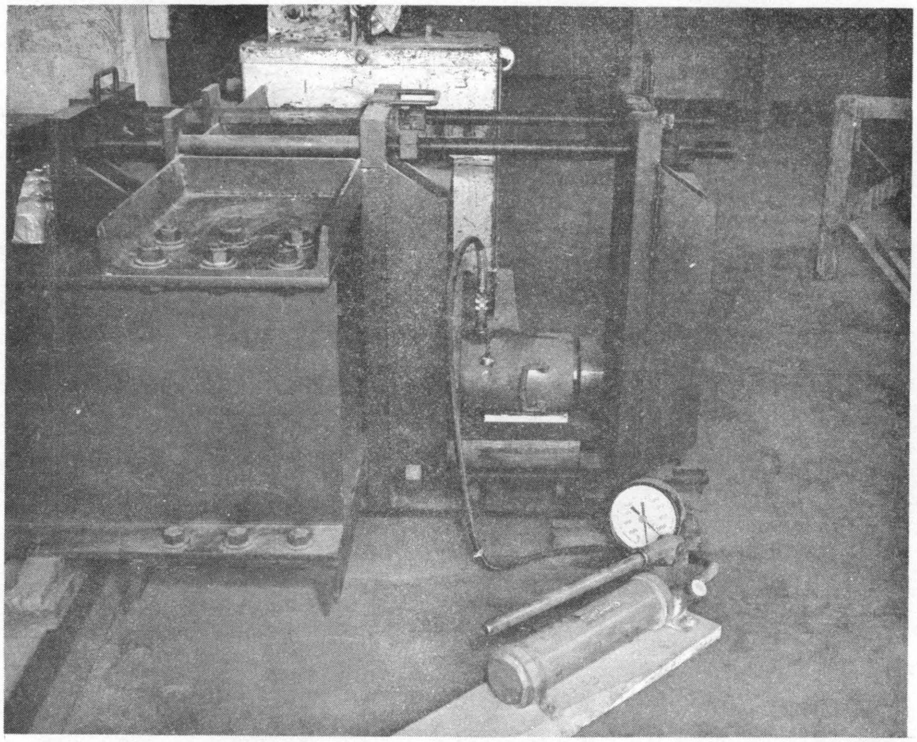

Fig. C Hydraulic Prestressing Equipment and Movable End Plates of Prestressing Unit

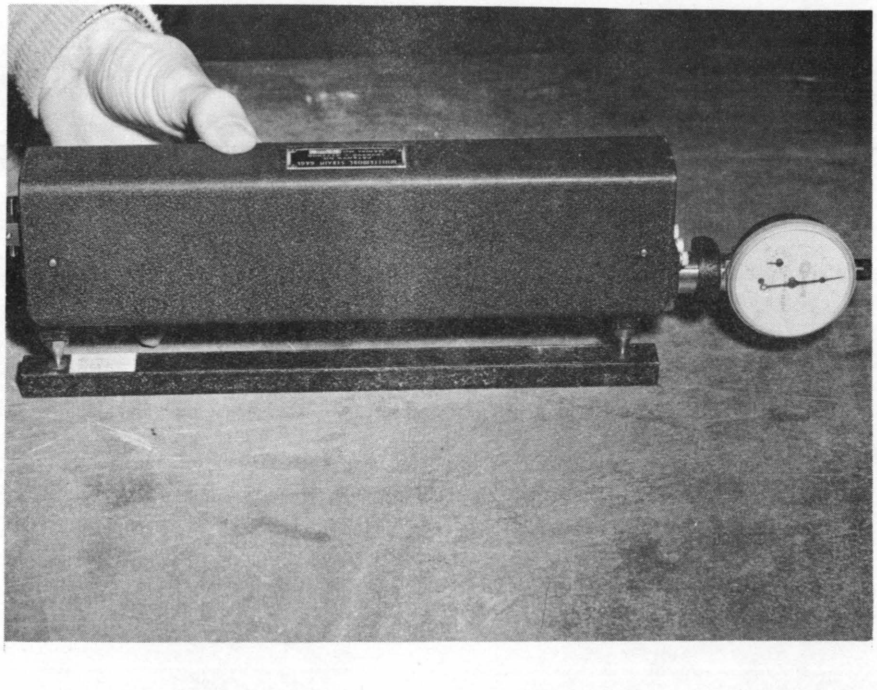

Fig. D Whitmore Mechanical Strain Gauge

The steel stranded cables were tested to determine their modulus of elasticity.

Concrete cylinders, made with the concrete for the beams, were tested to evaluate the modulus of elasticity of the concrete.

FABRICATION

The prestressed concrete specimens were 5.0 in. x 5.0 in. in cross section and ten feet in length. Each beam contained four 7/16 inch steel stranded cables, (Fig. E).

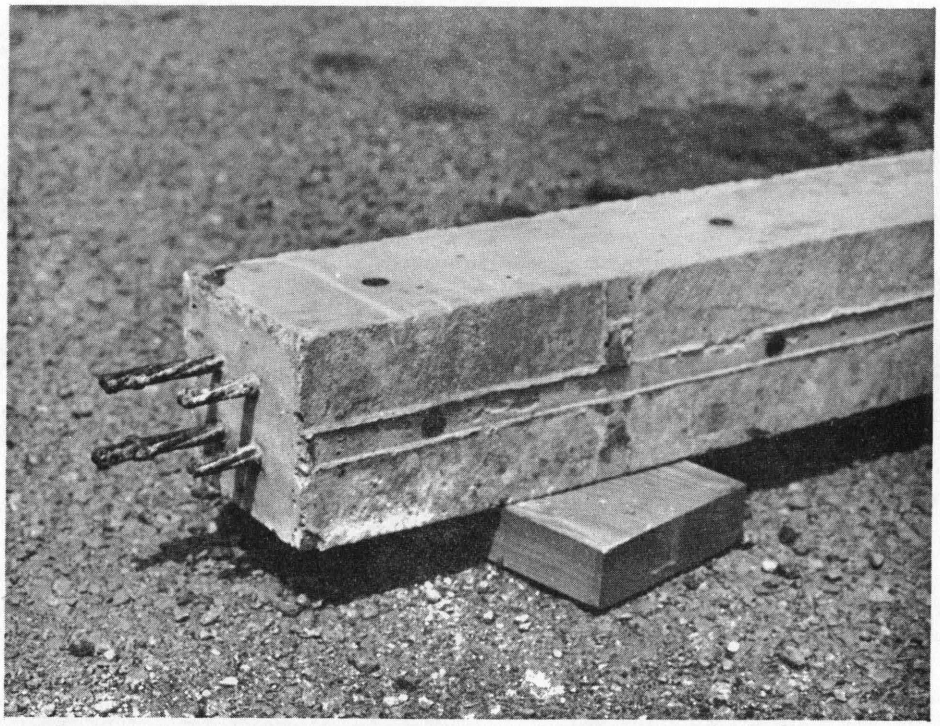

Fig. E Prestressed Concrete Test Specimen With Symmetrical Steel Placement

The four cables were threaded through the end plates of the prestressing bed and secured at each end with strand vises. A slight preload was applied to the individual cables to "set" the strand vises and put a uniform tension in all cables. Then the design pretensioning load was applied to the cables as a group. The design load for each cable was 19,900 pounds. The end plates were locked in place to maintain the pretensioning load on the cables.

Thermocouples were placed in the forms before the concrete was placed.

Brass reference buttons, which marked the ends of gauge lengths on the beam, were temporarily attached to the inside of the metal forms.

Concrete necessary to fabricate one beam was mixed in two separate batches. The slump was maintained at approximately $2\frac{1}{2}$ inches.

Steam curing did not start immediately after a beam was cast. Delay periods of various length were used. The delay periods ranged from 2 to 6 hours. Four of the beams were moist cured at room temperature. All curing periods were of approximately 48 hours.

Zero readings for the gauge lengths on the surface of the beam were taken immediately after the end of the steam curing and removal of the hood.

The load on the cables was slowly released after the zero readings were taken.

RECORDING OBSERVATIONS

The magnitude of the prestressing load was observed and recorded; this is the input load. Each of the four cables had a load cell on each end, the electrical strain indicating equipment determined the magnitude of the load applied to each cell. The average of the values indicated by the cells on each end of a cable was taken as the load on that cable.

A continuous record of the internal temperatures of the beam enabled evaluation of the rates at which the temperature was increasing and decreasing. From this information a temperature correction was made for the temperature induced change of gauge length during strain gauge readings.

Mechanical gauge readings of the ten inch gauge lengths on the surface of the beam, (Fig. E), were taken as soon as the hood was removed. The stress in the cables was released immediately after these zero readings were recorded. The final readings for strain were made immediately after the load was released so that the decrease in temperature of the hot beam would be as small as possible.

ANALYSIS

The total loss of prestress, expressed in percentage form, was computed as follows:

$$\text{TOTAL \% LOSS} = \frac{\text{INPUT LOAD} - \text{OUTPUT LOAD}}{\text{INPUT LOAD}} \times (100)$$

The total load on the cables, determined before steam curing started, was defined as the input load.

The output load was determined from the strains in the concrete indicated by the mechanical strain gauge. The strain used for computations was the average of the strains existing at the three middle cross sections since it is assumed that the full prestress force is developed near the center of the beam. Three strain readings were taken at each section: one on each side of the beam, and one on the top of the beam. This average strain value was located on the graph of stress vs. strain, for the concrete of the beam in question, to determine the prestressed induced compressive stress. Multiplying the indicated compressive stress by the net cross sectional area of the concrete beam gave the value of the force which caused the compressive stress. This is the output load.

The total loss of prestress occuring in each beam was computed and the results are tabulated in Fig. F. The total loss, averaged for each different delay period, is plotted in Fig. G.

The elastic loss of prestress (expressed as a percentage) was computed as follows:

$$\% \text{ ELASTIC LOSS} = \frac{\epsilon_c}{\epsilon_s} \times 100$$

Where ϵ_c = unit strain of the concrete, measured immediately after releasing prestress load.

ϵ_s = unit strain of steel cables initially, computed by; $\epsilon_s = \frac{S_s}{E_s}$

S_s = total load by area of 4 7/16" cables

Note that ϵ_c is taken to be the change of strain of the steel cable, caused by the elastic shortening of the concrete when the prestress load was transferred to the cured concrete. This is based on the assumption that the concrete and the cable act as a single unit after bonding has occured.

The elastic loss of prestress occuring in each beam was computed and appears in Fig. F. The elastic loss, averaged for each different delay period, is plotted in Fig. G.

The difference between the total prestress loss and the elastic loss was considered to be the thermal loss, (Fig. F). As a result of this assumption, any loss other than elastic loss appears in the value indicated as thermal loss.

In a series of special tests, steel cables in tension were subjected to a temperature increase equal to that used for steam curing. These tests indicate that an average of 8.3% of the

Fig. F
LOSS OF PRESTRESS

BEAM	IMPUT			OUTPUT			TOTAL LOSS		Es x 10^6 psi	% LOSS		Delay	BEAM
	Load lb.	Stress psi	Strain μ-in.	Load lb.	Stress psi	Strain μ-in.	lb.	%		Elastic	Therm.*	Hrs.	
1	72,300	165,800	5820	66,800	2720	608	5,500	7.6	28.5	10.4	-2.8	2.0	1
2	79,100	181,400	6360	68,800	2800	712	10,300	13.0	28.5	11.2	1.8	2.0	2
3	78,500	180,000	6320	--	--	717	--	--	28.5	11.3	--	2-2.5	3
4	79,800	183,000	6420	63,000	2567	726	16,800	21.1	28.5	11.3	9.8	3.0	4
5	80,900	185,600	6510	66,300	2700	711	14,600	18.0	28.5	10.9	7.1	3.0	5
6	78,200	179,400	6340	63,400	2583	670	14,800	18.9	28.3	10.6	8.3	3.5	6
7	84,100	192,900	6820	68,800	2800	695	15,300	18.2	28.3	10.2	8.0	3.5	7
8	80,400	184,400	6450	68,000	2770	688	12,400	15.4	28.6	10.7	4.7	4.0	8
9	77,700	178,200	6230	65,000	2650	627	12,700	16.3	28.6	10.1	6.2	4.0	9
10	81,200	186,200	6530	68,000	2770	667	13,200	16.3	28.5	10.2	6.1	6.0	10
11	81,100	186,000	6500	70,500	2870	766	10,600	13.1	28.6	11.8	1.3	N.S.	11
12	81,300	186,500	6930	75,900	3090	919	5,400	6.6	26.9	13.3	-6.7	N.S.	12
13	81,000	185,800	6910	72,900	2970	799	8,100	10.0	26.9	11.6	-1.6	N.S.	13
14	83,800	192,200	7140	65,800	2680	683	18,000	21.5	26.9	9.6	11.9	4.0	14
15	80,300	184,200	6560	71,000	2890	653	9,300	11.6	28.1	10.0	1.6	5.0	15
16	81,600	187,200	6660	71,300	2905	696	10,300	12.6	28.1	10.5	2.1	5.0	16
17	83,000	190,400	6780	75,400	3070	773	7,600	9.2	28.1	11.4	-2.2	5.0	17
18	82,100	188,300	6700	68,500	2790	694	13,600	16.6	28.1	10.4	6.2	6.0	18
19	83,000	190,400	7080	70,000	2850	719	13,000	15.7	26.9	10.2	5.5	6.0	19
20	81,500	186,900	6900	71,000	2890	691	10,500	12.9	27.1	10.0	2.9	6.0	20
21	80,000	183,500	6530	65,100	2650	686	14,900	18.6	28.1	10.5	8.1	4.0	21
22	84,000	192,700	7330	71,200	2900	760	12,800	15.2	26.3	10.4	4.8	N.S.	22
23	82,000	188,100	7150	72,500	2950	711	9,500	11.6	26.3	9.9	1.7	5.0	23
24	81,200	186,200	7630	64,800	2640	704	16,400	20.2	24.4	9.2	11.0	6.0	24
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	

(1) Observed	(4) (5) x 24.56	(7) (1) - (4)	(10) (6) ÷ (3)
(2) (1) ÷ A_s	(5) From Graph	(8) (7) ÷ (1)	(11) (8) - (10)
(3) (2) ÷ (9)	(6) Observed	(9) Test (Lab)	(12) Data

ASTM: A - 416 - 57T(8), 7/16 in. Cable, $A_s = 0.109$ in.^{2} (Nominal) $A_c = (5 \times 5) - 4(0.109) = 24.56$ in.^{2}

*Includes thermal and other losses not identified

LOSS OF PRESTRESS

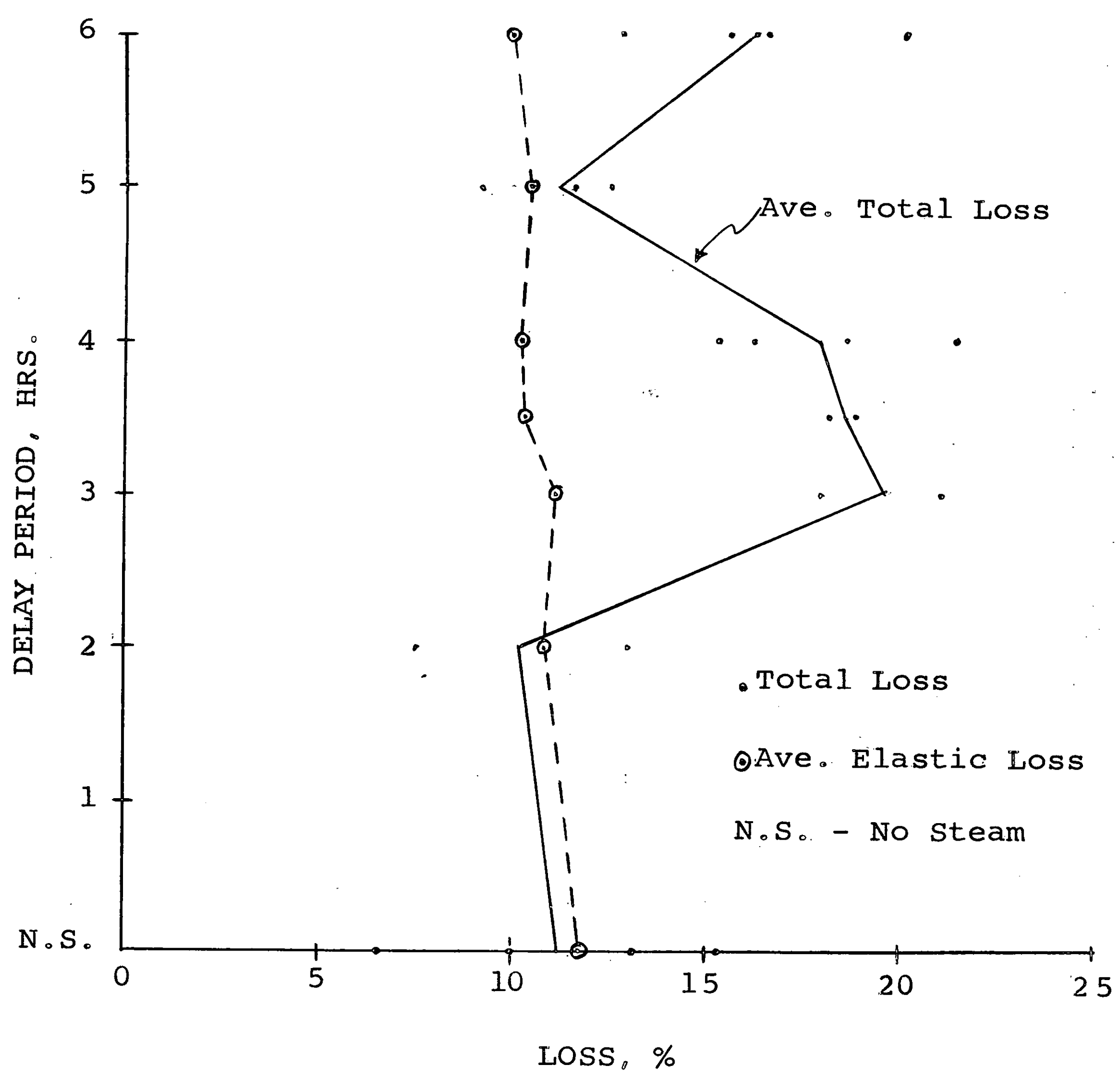

Fig. G

initial force on a cable was lost during the period of increased temperature. This loss includes cable creep and thermally caused relaxation of the stress in a cable.

The curing temperature of 180°F. furnished a wide range of temperature for the purpose of magnifying the effects of steam curing o~~f~~n the loss of prestress.

The loss of prestress due to steam curing, if determinable, should be fairly uniform. The increase in temperature for all steam cured beams was the same and for each beam the initial pretensioning load was approximately the same. The total loss of prestress for the twenty-four beams varied over such a wide range that no correlation between thermal losses and total loss is evident.

CONCLUSION

The results of this investigation indicate that substantial loss of prestress does occur regardless of the curing methods used.

Different delay periods, prior to steam curing, were used in an attempt to determine whether it is possible to obtain some bonding before thermal losses occur in the cables. The total losses for the beams of a given delay period were very inconsistent. The range of values was wide enough to rule out a practical comparison of their average with averages of other delay periods.

The average total loss for beams moist cured at room temperature was slightly less than the average value for steam cured beams. This comparison is also inadequate since in some instances the average total loss for steam cured beams was less than that of the moist cured beams.

The elastic loss of prestress, due to the elastic shortening of the concrete, was fairly consistent for all of the beams. The losses ranged from ten to twelve percent of the initial load.

The inconsistency of the apparent load at the opposite ends of a cable, as indicated by the load cells, was a major source of error. In some instances the indicated loads at each end of a cable varied by as much as 1,000 pounds.

Such things as possible change of length of the steel stress bed (during steam curing) and creep of the steel cables add to the difficulty of determining the losses caused by temperature increase.

While the loss of prestress caused by steam curing was not determined, it can be stated that, generally, losses in excess of those due to elastic shortening do occur.