THE EFFECTS OF PARTIAL PRESTRESSING
ON NEWLY CAST HAYDITE BEAMS

by

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INTRODUCTION

In keeping with the present day trends of reducing construction costs and conserving material, the use of lightweight aggregate in prestressed concrete structural members will yield a lighter member for an identical load situation, thus reducing the cross-sectional area and the amount of steel necessary to carry the lighter dead load. At the present time there is not sufficient information available on the behavior of lightweight aggregate under stress. This project used a lightweight expanded shale readily available in this area, and observed its behavior under a post-tensioned prestress load.

Originally, this project was to observe and record the loss of prestress force due to the shrinkage and creep in the steel and concrete in ten large specimens using a partial prestress of 251 psi in the concrete, and 30,751 psi in the steel for varying periods of time, and a final full prestress of 1000 psi in the concrete due to a stress of 132,000 psi in the steel. However, due to an error in the SR—4 strain gage reading from the jack rod, the first set of investigations used a final full prestress of 433 psi in the concrete due to a stress of only 53,200 psi in the steel. A second set of investigations on an additional ten specimens used the final full prestress of 1078 psi in the concrete resulting from 132,000 psi in the steel as originally planned.

Because of the importance of knowing the effects of different initial load intensities on the prestress loss, the first set of investigations was continued until around 140 days when the prestress-time curves became asymptotic, showing a small prestress loss over any further period of time. The first ten specimens were then dismantled, and the prestressing heads and equipment were used on the new specimens for the second set of investigations.

Besides the prestress loss history, this second set of investigations also included an observation of shrinkage plus plastic flow strain of the large specimens using plugs with a 20-in. gage length set in opposite sides of the specimens.

To aid in determining the concrete action without inherently including any steel action the creep strain, shrinkage strain and gross shrinkage plus plastic flow strain have been observed for small control beams made with the same concrete as four of the large specimens of the first set. These small beams were subjected, and still are, to a constant compressive stress of 1000 psi, the average strain being measured from plugs in the three-inch sides of the beams, and with an eight-inch gage length.

PREPARATION OF SPECIMENS

Specimens

The specimens for this project were prisms ten feet long, and with a six-inch square cross section (Fig. 1, Plate I). They were made with a lightweight, expanded shale aggregate concrete. A hole

EXPLANATION OF PLATE I

Fig. 1. Isometric view of large specimen showing duct for prestressing wires down the center.

Fig. 2. Isometric view of control beam.

PLATE I

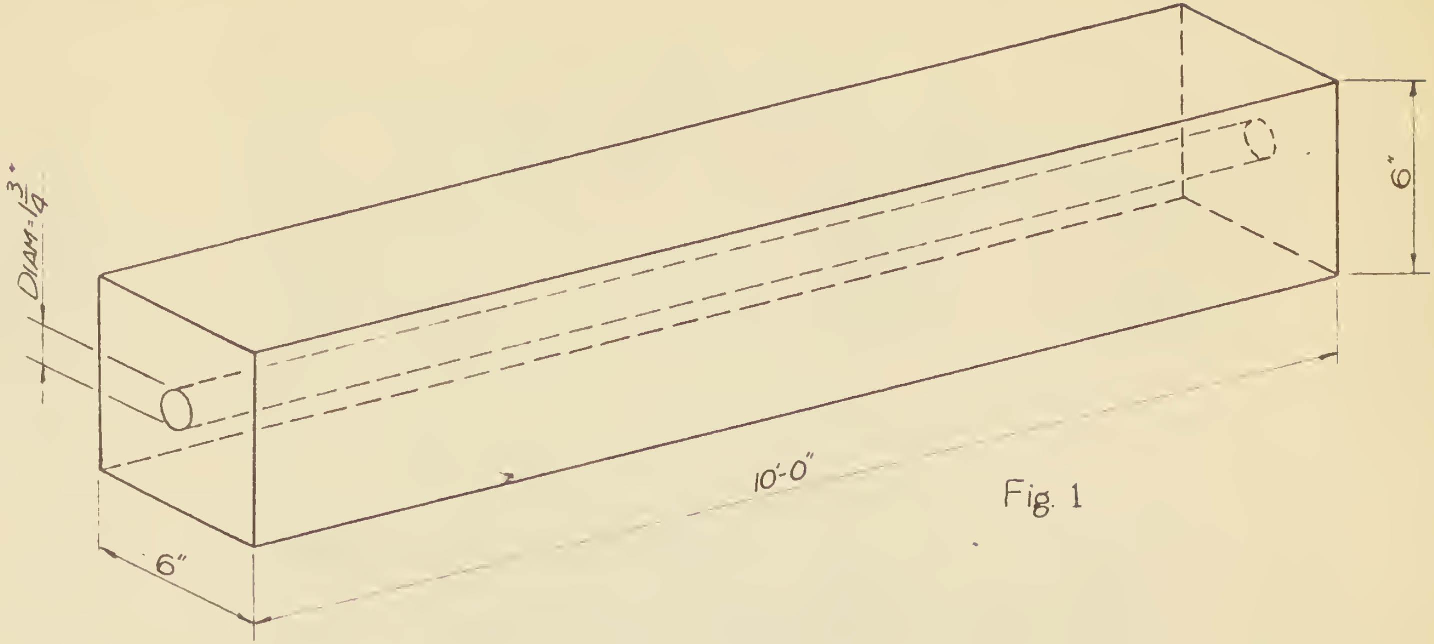

Fig. 1

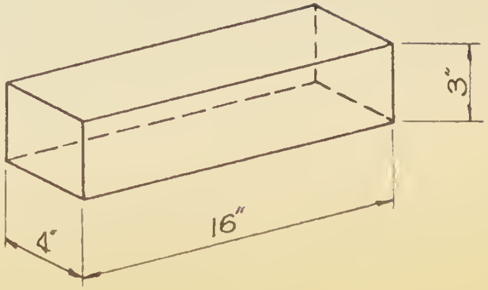

Fig. 2

was formed longitudinally down the center of each prism to receive the prestressing wires which were inserted after the specimen hardened. This hole was formed in two ways: In the first set of ten prisms a rubber hose was fixed in the form along the horizontal axis of the prism (Fig. 1, Plate II), and inflated to the 1 3/4 in. specified for the hole. After the initial set of the concrete, the hose was deflated and pulled out through a hole in the end of the form which was originally used to position the hose. In the second set of ten prisms a 1 3/4 in. iron pipe was used instead of the hose. This pipe was positioned coincident with the horizontal axis of the prism and, after the initial set, was withdrawn by pulling out through the hole in the end of the form. At each end of the specimen a 5 by 5 by 1/2-inch steel bearing plate was placed to distribute the compression load over the beam ends. A square coil of No. 9 wire was placed in the form at each end of the specimen. The specimens in each set were designated as CW 1, CW 2, . . . , CW 10, and were marked by imbedding in the fresh concrete a small copper tag stamped with the designation number.

For each 10-ft specimen, small 3 by 4 by 16-in. control beams (Fig. 2, Plate I), were poured from the same batch of concrete as the large specimen, and were used to determine the strength characteristics of the concrete, and for creep studies under constant load. These control beams were formed with standard metal forms for test beams, (Fig. 2, Plate II) and were designated as CW 1A, CW 1B, CW 1C, . . . , CW 2A, etc. Four control beams were poured for each large specimen of the first set, and two control beams for each specimen of the second

EXPLANATION OF PLATE II

Fig. 1. Wooden form for large specimen showing wire coils at beam end, and hose for duct.

Fig. 2. Standard metal form for 3 by 4 by 16-in. control beam.

PLATE II

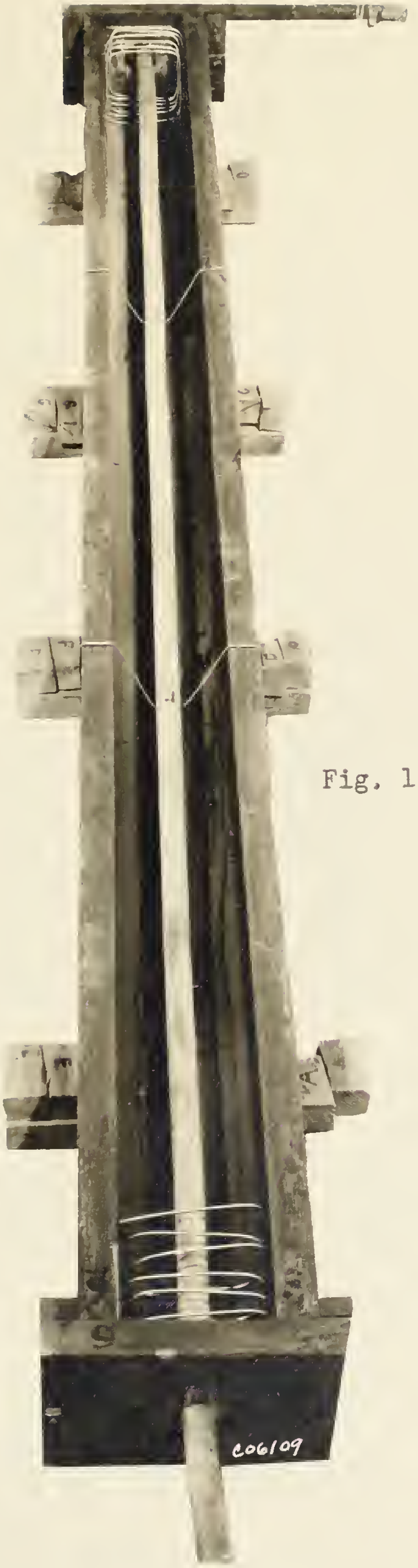

Fig. 1

set. In addition, two extra control beams were to simulate CW 2 and CW 5, and three extra for CW 7 and CW 9 of the first set to be used for the creep studies.

Concrete Mix Data

The mix approximated the plant mix of 1.1 cu yd of Carter-Waters B-X Haydite aggregate to 6.75 sacks of Incor high early-strength portland cement with 7.5 gal. of water per sack of cement. The 7.5 gal. of water was increased to 8.20 gal. of water per sack (except in CW 1, first set) because five extra pounds of water were added to increase workability of the concrete. The aggregate, which arrived from Carter-Waters with some moisture content, dryed considerably in the Lab before being used for the experiment. Even with this extra five pounds of water, the mix had a slump of zero to only one-half inch.

To insure the use of similar graded aggregate for each batch of concrete, five bags of Haydite were selected at random from the first 20 bags, and a sieve analysis run on this representative sample using a mechanical shaker. The gradation determined from this sample follows in Table 1:

Table 1. Sieve analysis of five bags of Haydite aggregate.

Sieve Size :	Cumulative Percent Retained
No. 4	21.4
8	48.3
16	71.2
30	88.4
-30	100.0

For the second set of specimens all twenty bags were mechanically sieved and recombined in the proper proportions shown in Table 2:

Table 2. Sieve analysis of 20 bags of Haydite aggregate.

Sieve Size	Pounds Retained	Pounds per Bag
No. 4	653	32.7
8	536	31.3
16	363	18.1
30	542	27.1
-30	98	4.9

The unit weight of aggregate, as shown below, was determined so the mix could be reduced to a mass-quantity basis:

Rodded weight,	66.2 lb per cu ft
Loose weight,	60.1 " " " "

Inasmuch as the aggregate from the stock pile is in the loose state, the loose weight of 60.1 lb per cu ft was used for the mix.

So the materials to be mixed could be weighed on a scale, the mass-quantities were figured as follows:

1.1 cu yd of aggregate = 1785 lb aggregate
(1.1 yd x 27 cu ft per yd x 60.1 lb per cu ft)

6.75 sacks cement = 635 lb cement
(6.75 sacks x 94 lb per sack)

7.5 gal. water per sack cement = 422 lb water
(7.5 gal. x 8.33 lb per gal. x 6.75 sacks)

The quantities used for each mix were,

236.8 lb of aggregate

$(236.8 \div 1785) \times 635$ lb = 83.85 lb cement

$(236.8 \div 1785) \times 422$ lb = 56.13 lb water (increased to 61.13 lb for greater workability)

This mix yielded almost five cubic feet of concrete of which approximately three cubic feet were needed to fill the specimen form and the control beam forms. The unit weight of this concrete averaged 100 lb per cu ft.

Molding Specimens

To make a batch of concrete, the cement and aggregate were first mixed dry for two minutes in the concrete mixer and then the water was added and the load agitated approximately three minutes, long enough for thorough wetting and mixing of the materials. Because of the light weight of the coarse particles, segregation was no problem.

The concrete was shoveled into the form and around the wire coils and inflated hose, and then was thoroughly vibrated into all void spaces with a hand vibrator. The top surface was hand troweled to a smooth, flat surface.

After the concrete had an initial set of approximately four hours, the hose (or pipe), which was lubricated with vegetable grease before the pouring procedure, was pulled out through the hole in the end of the form. The specimens, however, were not removed from their forms until the partial prestress had been applied.

The control beam forms were greased and filled with some of the remaining concrete of the batch and then were mechanically vibrated on a table vibrator. The exposed surface was hand troweled smooth and flat. The forms were removed after the concrete had set 24 hours.

EXPERIMENTAL PROCEDURE

Schedule of Prestressing Large Specimens

The specimens numbered CW 1 through CW 8 were given a partial prestress of 251 psi at two days of age. These two days allowed the beams to acquire a permanent set before a load was applied. No partial prestress was applied to CW 9 and CW 10. The final prestress of 433 psi in the first set, and 1078 psi in the second set was applied as shown in Table 3.

Table 3. Age of beam when given partial and final prestresses.

Specimen Designation	Partial Prestress in days	Duration of Partial in days	Final Prestress in days
CW 1	2	1	3
CW 2	2	2	4
CW 3	2	3	5
CW 4	2	4	6
CW 5	2	5	7
CW 6	2	12	14
CW 7	2	19	21
CW 8	2	26	28
CW 9	None	-	7
CW 10	None	-	14

Schedule for Control Beams

The A, B, C and D control beams were tested in flexure in a simple-beam testing jig[1], loaded at the center of a 14-in. span, to determine the modulus of rupture, and were tested in a modified cube compression[2] test to determine the compressive strength. The A beams for CW 1 through CW 8 were tested at the time of partial prestressing of the large specimen -- two days of age. All of the B and C beams were tested at the time the final prestress was applied to their corresponding large specimens. All of the D beams and the A beam for CW 9 and CW 10 were broken at 28 days of age. The strength data gathered from these control beams are shown in Appendix B.

Control beam E was partial and fully prestressed at the same time as the corresponding large specimens, CW 2, CW 5, CW 7 and CW 9, by a calibrated spring axial squeezing device, Plate III, and was used to determine the gross -- shrinkage plus plastic flow -- strain. Beams F and G had no stress applied, and were used to determine the shrinkage strain. The creep strain, shown in Tables 37 through 40, is the shrinkage strain minus the gross strain.

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[1] Proceedings. American Society for Testing Materials, Vol. 30, Part II, page 589 (1930).

[2] Koenitzer, L. H., "Proposed Methods of Making Compression Tests on Portions of Concrete Beams from Flexure Tests, "Proceedings. Am. Soc. for Testing Materials, Vol. 34, Part II, page 406 (1934).

EXPLANATION OF PLATE III

Spring loaded axial squeezing device with a 3 by 4 by 16-inch control beam in position to be loaded.

PLATE III

Method of Prestressing

The Prestressing Incorporated six-wire system was used to supply the post-tensioned prestress load. The high-strength steel from the Union Wire Rope Company, with a diameter of 0.250 in. and minimum ultimate strength of 220,000 psi, was inserted in the holes formed through the large specimens. At one end, a PC-11 six-wire head, a PC-12 six-wire plug, and a PC-14 split-pressure block held the wire ends fixed, and transferred the stress to the steel plate on that end of the specimen. At the other end of the specimen there was a threaded six-wire head, Plate IV, designed by the Applied Mechanics Department of Kansas State College. This head was screwed down each time the wire was pulled further through the specimen which amounted to a strain of approximately 3/4 inch with a stress of 132,000 psi in the steel. The force for stressing the wire was supplied by a 30-ton, Center-Pull, Simplex Jack and Pump (Plate V), and was attached to the wires by a calibrated center-pull rod threaded into a pulling head (made by Fred Budden, machinist, Department of Applied Mechanics, Kansas State College) which screwed onto a modified PC-8 pulling unit (Plate IV).

Recording Prestress Losses

At arbitrary intervals of time, the prestress remaining in the concrete was recorded by measuring the stress in the prestressing wires. When measuring this stress, the wires were stretched by the jack until

EXPLANATION OF PLATE IV

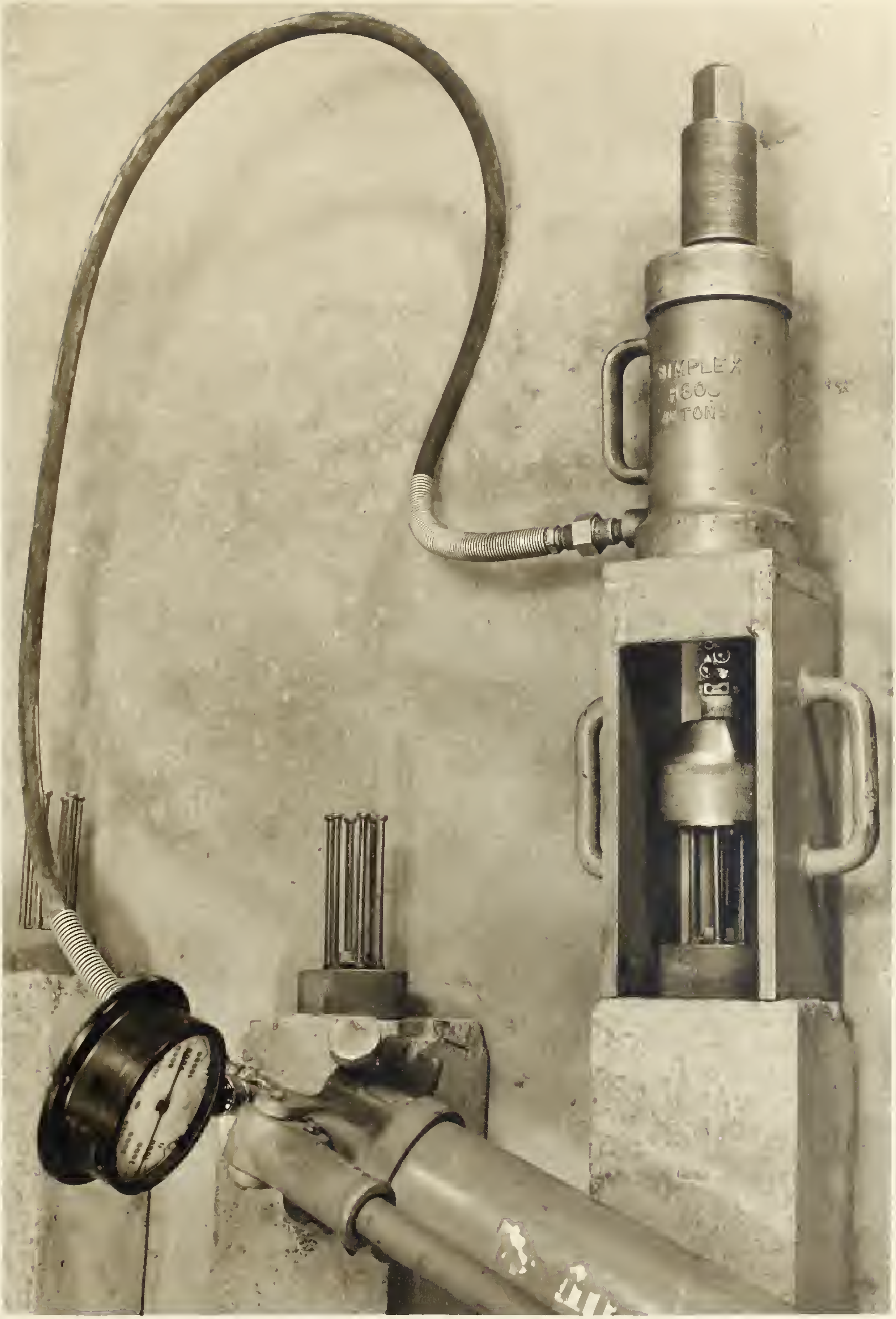
Exploded view of prestressing hardware for Prestressed Incorporated six-wire system.

PLATE IV

EXPLANATION OF PLATE V

Jack mounted on end of large specimen and showing working arrangement of prestressing hardware.

PLATE V



the threaded head unseated itself from the steel plate on the end of the specimen, and could be turned back and forth by hand. At this point, the load was transferred from the wire to the specimen through the legs of the jack. The pressure in the jack was then slowly released, and the strain (or gage) reading recorded at the exact time the threaded head tightened against the steel plate. At this point the load was transferred from the wires through the threaded head to the specimen. The validity of this method is discussed in Appendix A.

On the first set of large specimens, the strain in the calibrated center-pull jack rod was read using a Baldwin SR-4 Model K Strain Indicator that was wired to SR-4 strain gages on opposite sides of the jack rod. The prestress in the concrete was then calculated using a load value for the jack rod, taken from a load-strain curve that was experimentally determined with a hydraulic testing machine. Figures 6 through 15 give the prestress history of this first set of ten specimens, and were drawn using prestress values taken from Tables 7 through 16 in Appendix, which show the jack rod strain, the prestress in the concrete and the loss of prestress.

On the second set of specimens, the value from a 10,000 lb hydraulic gage mounted on the pump was recorded. The prestress in the concrete was then calculated using a load value taken from a load-gage reading curve that was experimentally determined. Figures 16 through 25 give the prestress history of this second set of ten specimens, and were drawn by using prestress values taken from Tables 17 through 26. For the first set, the stress was measured very frequently as shown by the large number of readings on the stress, stress loss and age tables. However, since the stress loss did not, in general, change abruptly with time but followed a hyperbolic pattern, the number of stress readings was considerably reduced for the second set.

Strains were also measured on the second set by using a 20-inch Berry Gage and plugs, with a 20-inch gage length, set in opposite sides of the specimens:

$$\text{strain } 10^{-6} \text{ in/in.} = \frac{\text{increment in gage reading}}{20''(\text{gage length}) \times 5.291(\text{gage factor})}$$

The strain history appears as a dashed line on Figs. 16 through 25, and was drawn using values from Tables 27 through 36.

EXPERIMENTAL RESULTS

To arrive at some easily readable results (Fig. 1) gives an analysis of the stress histories of both sets of specimens showing the prestress remaining at various ages. Examination of Fig. 1 for the first set indicates that, except for CW 5, each beam that received a partial prestress experienced a smaller final prestress loss as the duration of the partial prestress increased. For instance, at 140 days, CW 1 had a prestress remaining of approximately 190 psi or a prestress loss of 240/433 = 55 percent, whereas, CW 4 had 210 psi remaining or a loss of 223/433 = 52 percent. To qualify the results, however, allowance must be made for the fact that the age in days also includes the time of partial prestressing and, therefore, each successive final prestress had been applied for correspondingly shorter periods of time. Nevertheless, in beams CW 1 through CW 4, in which the durations of final prestress differed successively by only one day, being 1, 2, 3 and 4 days, respectively, there was a marked decrease of prestress loss.

To understand what effect a longer period of partial prestressing will have, look at CW 6 and CW 7 which were fully prestressed at 14 and 21 days of age, respectively; realizing that the 100-day reading then corresponds to an approximate duration of final prestress, indicated by the 80-day readings of Cwl through Cw 5, Fig. 1 shows that both the former had lost approximately 160 psi at 100 days, which is 10 percent less stress loss than the average 200/433 = 47 percent total loss at 80 days in CW 1 through CW 5. This ten percent decrease in stress loss must be due to the increased duration of the partial prestress.

Comparing CW 5 with CW 9, which had no partial load applied but was prestressed at 7 days of age, there was, at 80 days, over 200 psi lost in CW 5, whereas, there was 223 psi lost in CW 9. Hence, the partial in CW 5 has diminished the stress loss and this occurred even with CW 5 not following the trend set by CW 1 through CW 4. If CW 5 had lost only 173 psi, as did CW 4 at 80 days, the stress loss would have been 12 percent less than the loss in CW 9. Between CW 6 and CW 10, which had no partial load, and was prestressed at 14 days, there was hardly any difference in the stress losses. Hence, either one or both of these comparisons may not be valid.

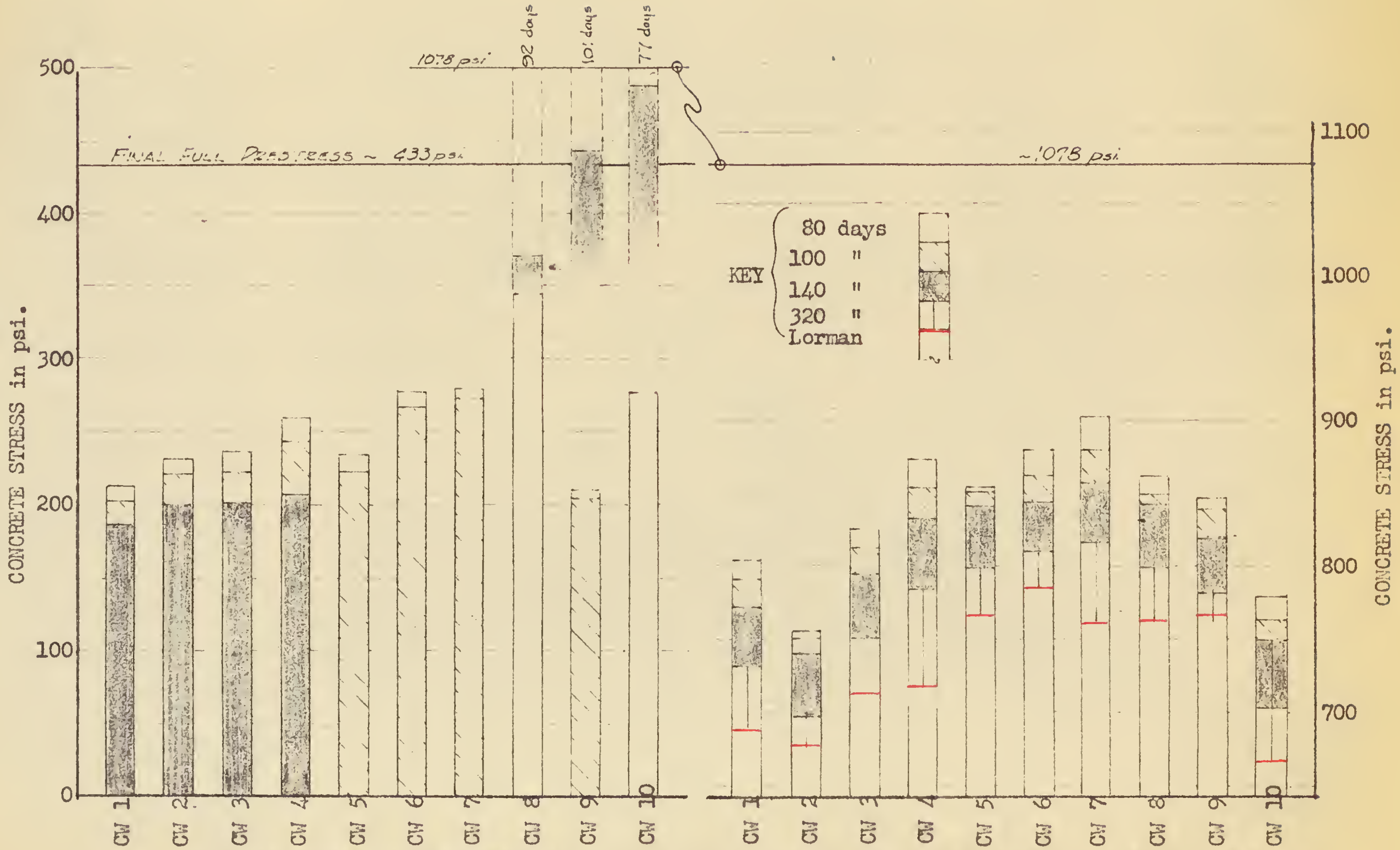


Fig. 1. Concrete stress in specimens at 80, 100 & 140 days of age of both sets and also 320 days and Lorman prediction of ultimate prestress loss for second set.

In more notable terms, at the end of 140 days for CW 1 there was 0.45 x 53,200 = 23,900 psi stress remaining in the steel which is a 53,200 - 23,900 = 29,300 psi loss of steel stress. This loss amounts to a large percentage (56 percent) of the initial 53,200 psi steel stress, but would be a small percentage (22.2 percent) of a 132,000 psi initial steel stress. For CW 6 there was a 0.37 x 53,200 = 19,700 psi loss in the steel or, at the 132,000 psi level, a 48,800 psi loss of stress.

The second set shows the same general trend as the first set. Except for CW 2, which had a loose end plate, and therefore gave erratic results, CW 1 through CW 5 showed a decrease in the prestress loss as the age of duration of partial increased. At 140 days, CW 1 had lost 308 psi in the steel. CW 4 had lost 228 psi = 21.2 percent which is a 28,000 psi stress loss in the steel.

At 100 days, CW 6 had lost 218 psi, and CW 7, 198 psi; both readings smaller by an average of 7.5 percent than the corresponding 80-day stress losses in CW 1 through CW 5. The steel loss for CW 6 was 0.202 x 132,000 = 26,700 psi. Hence, once again the duration of partial prestress of over 12 days appreciably reduced the final prestress losses.

Comparing CW 5 with CW 9, there was only a slight difference in the stress losses, CW 9 losing 10 psi more than CW 5. Between CW 6 and CW 10 there was a large difference, but CW 10 was not a true indication because the steel bearing plate was badly skew to the plane of the end of the specimen.

At 320 days, all of the specimens appeared to be following the pattern set by the young ages. The greatest loss was evident for CW 2 which had remaining 690 psi or a loss of 36 percent, which was a 48,000 psi steel stress loss. But the curves shown in Figs. 16 through 25 indicate that the ultimate loss would be much greater than at 320 days.

In order to predict what ultimate prestress loss might be expected, William Lorman's[3] method for determining creep in concrete under a constant load was used. The ultimate stress losses are represented in Fig. 1 by the red lines, and were gathered from Figs. 26 through 35 which are the graphical determinations using values for e in the abscissa equation $V = \frac{tS}{e}$ taken from Tables 17 through 26: e is prestress loss after final prestressing, t is the time in days after the final prestress, and S is the final prestress, 1078 psi. This method is, of course, not completely accurate but is "a simple and practical method for determining the creep of . . . concrete" and was conservative in this case because the prestress load diminished, whereas, the Lorman predictions were based upon a constant load.

In general, the red lines seem reasonable and follow the pattern set by the early ages, even though CW 7 and CW 8 did not comply, but indicated that the creep loss had not stopped at 320 days. CW 2, for instance, lost an additional 19 psi, giving 398 psi lost = 36.9 percent this is a 47,700 psi steel loss. CW 7 had lost an additional 55 psi

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[3] Lorman, William R. "The Theory of Concrete Creep." Proceedings, Am. Soc. for Testing Materials. 40:1082-1086. (1940).

which, however, still results in only a 29.2 percent loss.

This long-time loss of prestress was due to two strain phenomena; shortening of the concrete, and lengthening or relaxation of the steel. Up to the time of this thesis, the Union Wire Rope Company had published no data describing the long-time strain action of the prestressing wires. Therefore, these prestress loss analyses were based on the premise that all of the strain occurred in the concrete.

Strain in concrete is due to elastic shortening, shrinkage, creep growth, swelling, etc. The method employed in this thesis measured total strain and, hence, made no differentiation as to what part of the prestress loss of any one beam was attributed to creep and to shrinkage. The elastic strain only entered the picture during a short time subsequent to applying the prestress. It did not have a great importance after two or three days. Shrinkage, on the other hand, accounted for a large part of the long-time prestress but was probably independent of the load intensity, and would have occurred even if there had been no load applied. To estimate how much of the gross strain was due to shrinkage and how much to creep, the gross, shrinkage and creep (gross minus shrinkage) strain histories of control beams for CW 2, CW 5, CW 7 and CW 9 were plotted graphically in Figs. 2 through 5 using data from Tables 37 through 40.

Figures 2, 3 and 4 show that shrinkage strain amounted to approximately 3/5 of the gross strain. This shrinkage might well occur with identical values independently of any increase of final prestress. Creep accounted for approximately 2/5 of the gross strain, and it

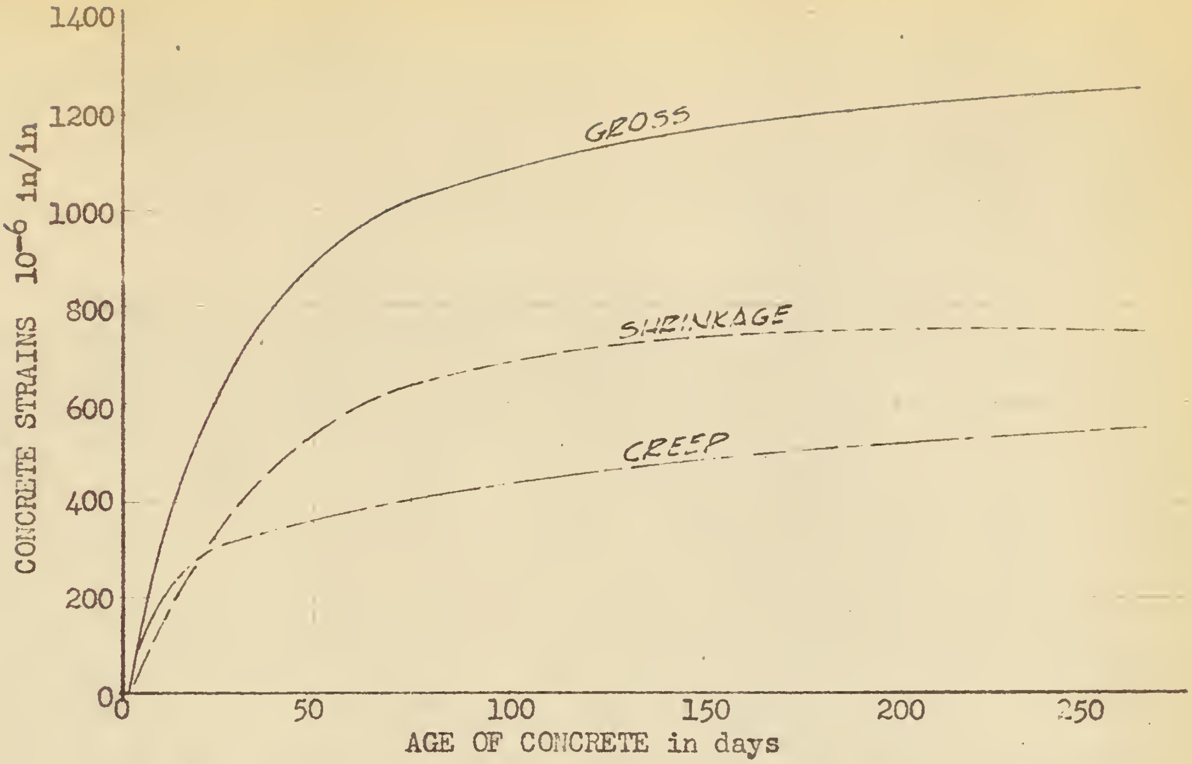

Fig 2. Gross, shrinkage and creep strain of CW 2 control beams.

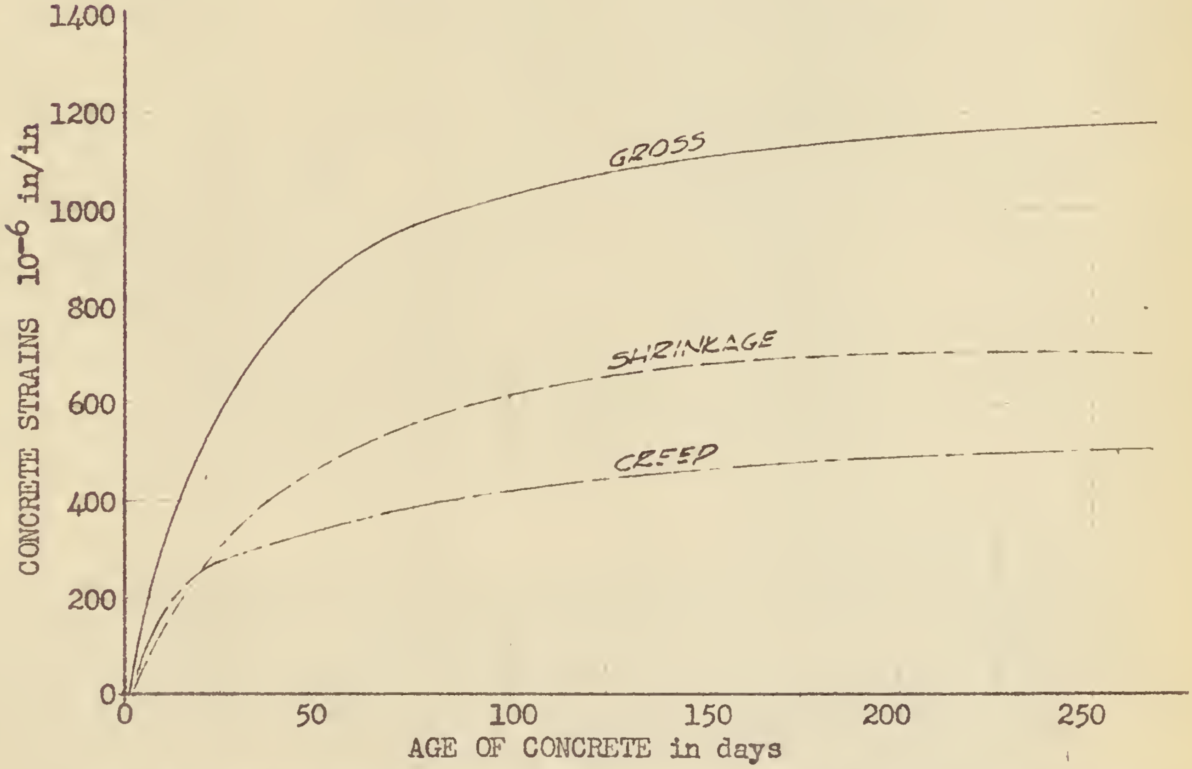

Fig 3. Gross, shrinkage and creep strain of CW 5 control beams.

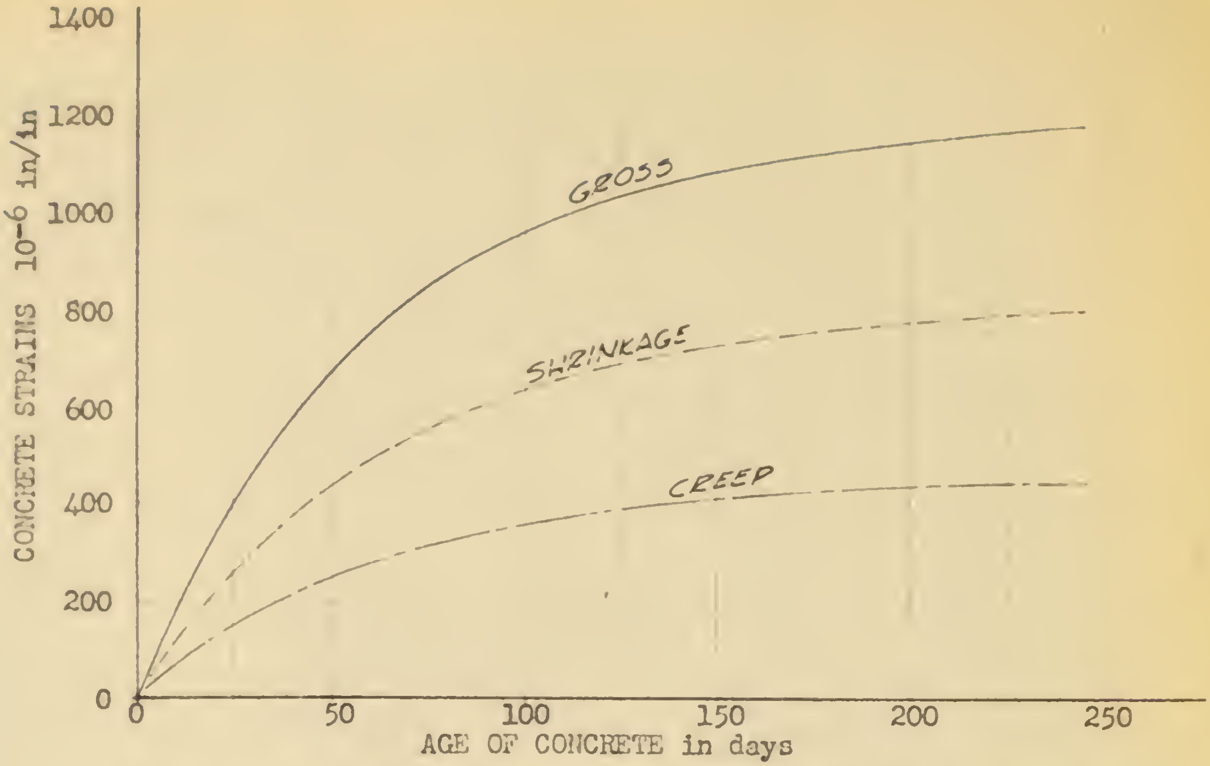

Fig 4. Gross, shrinkage and creep strain of CW 7 control beams.

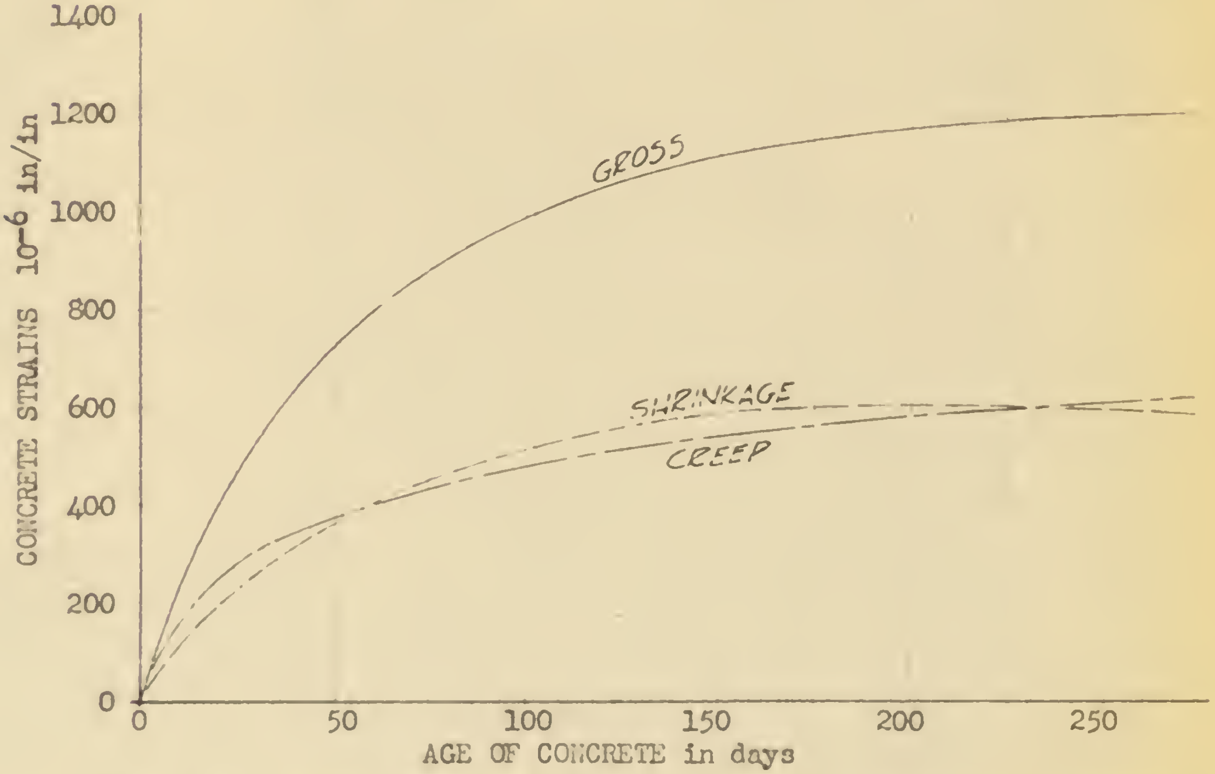

Fig 5. Gross, shrinkage and creep strain of CW 9 control beams.

probably would be reasonable to assume that the total creep would increase proportionately with an increase of final prestress. Figure 5 shows that shrinkage and creep are almost equal. Realizing that CW 9 had no partial applied but was given the whole final prestress at seven days of age, this equality may or may not be a fact common to the no-partial load situation. In any case, observations on only one beam would not decide a general trend. The important fact shown in Fig. 5 was that, when compared with CW 5 (Fig. 3), the creep of CW 9 is noticeably greater than the creep of CW 5 which had the partial prestress applied five days. CW 7 whose partial load was applied for 19 days, had the smallest creep strain.

An attempt to correlate the small control beams with respect to the large specimens was made by using the strain of the large specimens (Figs. 16 through 25). However, the fact that this strain continued at a rate which exceeded the stress loss rate, which had somewhat leveled off, is suspicious because the strain should have leveled off proportionately with the prestress loss. Consequently, the strain readings were not considered reliable. However, a Lorman type of prediction, using strain values (e = strain after final prestressing), Tables 27 through 36, was drawn, Figs. 26 through 35. Table 4 tabulates the ultimate strains and compares their steel stress losses with the corresponding steel stress losses that accompany the prestress loss values. CW 6 showed the greatest ultimate strain equal to 1860×10^{-6} in/in., an ultimate stress loss of $28 \times 1860 = 52{,}100$ psi which greatly exceeded the 35,800 psi ultimate stress loss determined for prestress by the Lorman method. Several other beams followed this pattern. This is not a general trend, however, as CW 1, CW 2 and CW 3 had lesser strain steel loss than prestress steel loss. Actually, in the case of these three, the higher prestress steel loss could be explained by introducing the possibility of creep in the steel which would cause a prestress loss without an accompanying strain of the concrete. But the other beams, which followed a reverse situation, discredited the validity of the strain readings.

Table 4. Ultimate steel stress loss determined by strain compared with the loss determined by prestress loss percentage using values from Lorman's method.

Beam No.	Ultimate Strain 10^{-6} in/in.	Steel Stress Loss		Prestress Loss percent
		Strain x E*	% x 132,000 psi	
CW 1	1390	38,900	47,500	36.0
CW 2	1350	37,800	48,700	36.9
CW 3	1250	35,000	44,600	33.8
CW 4	1720	48,200	44,000	33.3
CW 5	Readings too erratic		37,900	28.7
CW 6	1860	52,000	35,800	27.1
CW 7	1400	39,200	38,600	29.2
CW 8	1710	47,900	38,300	29.0
CW 9	1470	41,200	37,700	28.6

*E of the steel equals 28 x 10^6 psi.

CONCLUSIONS AND RECOMMENDATIONS

From the foregoing discussion of test results, it may be concluded that a partial prestress that is applied for reasonable lengths of time will effectively reduce the prestress loss. CW 5, CW 6, CW 7 and CW 8 of the second set, all with reasonable durations of partial load, had a prestress loss limited to within 320 psi in the concrete or 320/1073 x 132,000 = 39,200 psi in the steel. It is evident that (Fig. 1) the general trend is a lessening of prestress loss accompanying an increase in duration of partial but it is not evident, within the limits of this project, which age of partial prestress would result in a commercially economical "happy medium" between storing time while the partial was acting and prestress loss limiting design flexibility. Actually, this excessive prestress loss (29.2 percent in CW 7 as compared with approximately 12.6 percent in hard rock concrete) seems to be the limiting factor against using lightweight Haydite aggregate for prestressed members because the other desirable qualities — strength, wearability, durability, weathering resistance — compare favorably with those available in hard rock concrete.

From the engineering viewpoint, these investigations indicate that, for a concrete stress of 1000 psi due to a steel stress of 132,000 psi applied after a partial prestress of not less than six days, the wires would lose a maximum of 30.4 percent of the initial stress, leaving a residual stress in the steel of 132,000 - 40,000 = 92,000 psi for design. This, however, will be an ultra conservative estimate in view of the fact that the wires were located through the center of a uniformly loaded specimen, whereas, in a loaded flexural member, the wires will be along the tension side of the member at the location of a low concrete stress and, furthermore, that the maximum 1000 psi in the concrete will act only at the extreme compression fiber. Since the creep in the concrete will vary in a straight line relationship from the 1000 psi stress level to the minimum stress level at the tension side of the member, the stress loss at the steel level, due to creep in the concrete, will be a minimum. Consequently, the stress loss in the steel would not approach the 30.4 percent maximum; the degree of conservatism could only be found by conducting tests on actual loaded members. To compete, however, with building methods already in use, some way of utilizing the full working stress of 132,000 psi in the steel should be found. From the writer's standpoint, there may not be any objection to applying an initial stress exceeding 132,000 psi, up even to 172,000 psi, whereby the 40,000 psi loss would leave the full working stress in the wire. But there would be much public and legal misapprehension about using a member so initially prestressed in a structure. Hence, further tests using initial wire stresses exceeding 132,000 psi should be attempted. Obviously, from the action of the 1078 psi load intensity compared with the 433 psi load intensity, (Fig. 1), the creep and resulting losses would be proportionately greater. Not so obvious is the action, detrimental or not, this higher stress would have on the steel, a question that could be answered by unstringing the specimens and checking the steel for safe usability.

If other tests are conducted, several items should be improved: These are,

1. End plates with the same area as the cross section of the specimen — 6 in. by 6 in. in this project,

2. A more reliable way of measuring strain,

3. A more dependable way of indicating the instant the wire stress is transferred through the prestressing hardware to the steel bearing plate.

ACKNOWLEDGMENTS

For their guidance and cooperation during this study, the writer wishes to express his appreciation to Dr. Dale R. Carver, Associate Professor of Applied Mechanics, Kansas State College, who gave aid in setting up this project, and in compiling and investigating data, to Professor C. H. Scholer, Head of the Department of Applied Mechanics, Kansas State College, who aided in drawing conclusions from this project, and to E. R. Chubbuck, Assistant Professor of Applied Mechanics, Kansas State College, who furnished strain data.

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Lorman, William R. "The Theory of Concrete Creep." Proceedings, Am. Soc. for Testing Materials. 40:1082-1086. 1940.

Proceedings, Am. Soc. for Testing Materials. Part II, 30:589. 1930.

APPENDIX

APPENDIX

Equipment

Simplex R306 30-ton Center Pull Jack and Pump, Templeton, Kenly and Company, Ltd., Chicago 44, Illinois.

Ashcroft Slotted Link Pressure Gage, 0-10,000 lb capacity (mounted on Simplex Pump).

H. C. Berry 20-in. Mechanical Strain Gage, constant = 1.5291, with a B. C. Ames Company 1/1000 in. Ames Dial Gage.

Baldwin SR-4 Model K Strain Indicator, Baldwin Southwark Division, Baldwin Locomotive Works, Philadelphia, Pennsylvania; made by the Foxboro Company.

Baldwin Southwark Division AC Power Supply for SR-4 Strain Indicator, Serial No. 485071-6, 115 volts, 60 cycle.

Rex 3 1/2 Sack Mixer, sold by Victor L. Phillips Construction Machinery and Supplies, Kansas City, Missouri, or Wichita, Kansas.

Electric Vibrator Model 1, Serial No. 12, Viber Company, Ltd., Los Angeles, California.

APPENDIX

Validity of Calculated Stress at Instant Threaded Head Apparently Tightens

This discussion is to determine whether or not the strain measured at the instant the threaded head tightened (to hand turning) against the bearing plate on the end of the ten-ft specimen in the actual strain in the wires. The reason for making the statement that the strain may not be what it seems is that, after the threaded head apparently tightened, the wires seemed to move or shorten further than the shortening already needed to tighten the head. This movement is noticeable to the eye, and can be attributed to two things: (1) the buttons on the wires are reseating themselves into the locking head and plug, and (2), the head is flattening itself against the end bearing plate.

Number one is possible because when the wires are stretched with the jack and the threaded head is loose and can be turned by hand, only friction holds the wires seated in the locking head and plug. When the wires are stretched, their diameter may decrease slightly and, therefore, the buttons have a tendency to loosen away from the locking hardware. When the jack pressure is released, the wire friction carries the threaded head tight enough against the bearing plate to resist movement by hand.

Number two occurs when the bearing plate is slightly non coincident with the plane of the end of the beam and, hence, the threaded head seems tight when only one edge is actually tight against the bearing plate. Further release of the jack pressure allows the wires to pull the threaded head tight against the plate.

If the total additional shortening (strain increment) is as much as 1/16 in., the stress loss in the steel, according to Hooke's Law, amounts to

$$S = Ee = \frac{\Delta L}{L} = 28 \times 10^{6} \; \frac{1/16}{14 \times 12} = 14{,}000 \text{ psi}$$

which is a stress loss in the concrete of

$$\frac{14{,}000}{132{,}000} \times 1078 = 114 \text{ psi.}$$

However, this loss is partially recovered because the area of the 3/4 in. duct down the center of the specimen diminishes the total 36 sq. in. by

$$\frac{\pi d^{2}}{4} = \frac{\pi}{4}\,(1.75)^{2} = 2.4 \text{ sq. in.}$$

This reduction of area increases the stress in the concrete by

$$\frac{1.4}{36} \times 1078 = 72 \text{ psi.}$$

Hence, the magnitude of error in measuring strain and then calculating the stress is approximately 42 psi or $(42 \div 1078) \times 100 =$ 4.5 percent, which is 5900 psi in the steel. This error, of course, is not likely to be this large because the 1/16 in. additional shortening is extreme.

Table 5. Strength data from control beams, first set.

Specimen No.	Date Made	Partial Prestress			Final Prestress			28-Day	
		Age in Days	Mod. of Rupture psi.	Compr. Str. psi.	Age in Days	Mod of Rupture psi.	Compr. Str. psi.	Mod. of Rupture psi.	Compr. Str. psi.
	1953								
CW 1	Sept. 29	2	683	3330	3	594	3735	507	4210
CW 2	Sept. 29	2	571	2605	4	516	3115	624	3935
CW 3	Oct. 5	2	525	2550	5	583	3805	554	4760
CW 4	Oct. 6	2	648	2990	6	630	4090	606	4980
CW 5	Oct. 6	2	583	3000	7	571	4240	536	4600
CW 6	Oct. 12	2	594	3615	14	542	4425	536	5030
CW 7	Oct. 13	2	606	3235	21	664	4825	454	4638
CW 8	Oct. 22		677	2955	28	571	4859	560	4467
			One Day						
CW 9	Oct. 13	None	526	2745	7	653	4605	711	5358
CW 10	Oct. 22	None	525	2725	14	548	4950	455	4550

Table 6. Strength data from control beams, second set.

Speci- men No.	Date Made	Partial Prestress			Final Prestress		
		Age in Days	Mod. of Rupture psi.	Compr. Str. psi.	Age in Days	Mod. of Rupture psi.	Compr. Str. psi.
CW 1	Feb. 27	2	583	3638	3	600	4361
CW 2	Mar. 2	2	292	2196	4	437	4133
CW 3	Mar. 13	2	595	3633	5	510	4154
CW 4	Mar. 9	2	641	4755	6	408	5113
CW 5	Mar. 10	2	700	4667	7	466	4871
CW 6	Mar. 4	2	321	3236	14	233	3242
CW 7	Mar. 11	2	700	4075	21	431	5629
CW 8	Mar. 3	2	548	3796	28	577	5762
			28-Day				
CW 9	Mar. 6	None	58	4142	7	396	3397
CW 10	Mar. 17	None	524	5380	14	863	4758

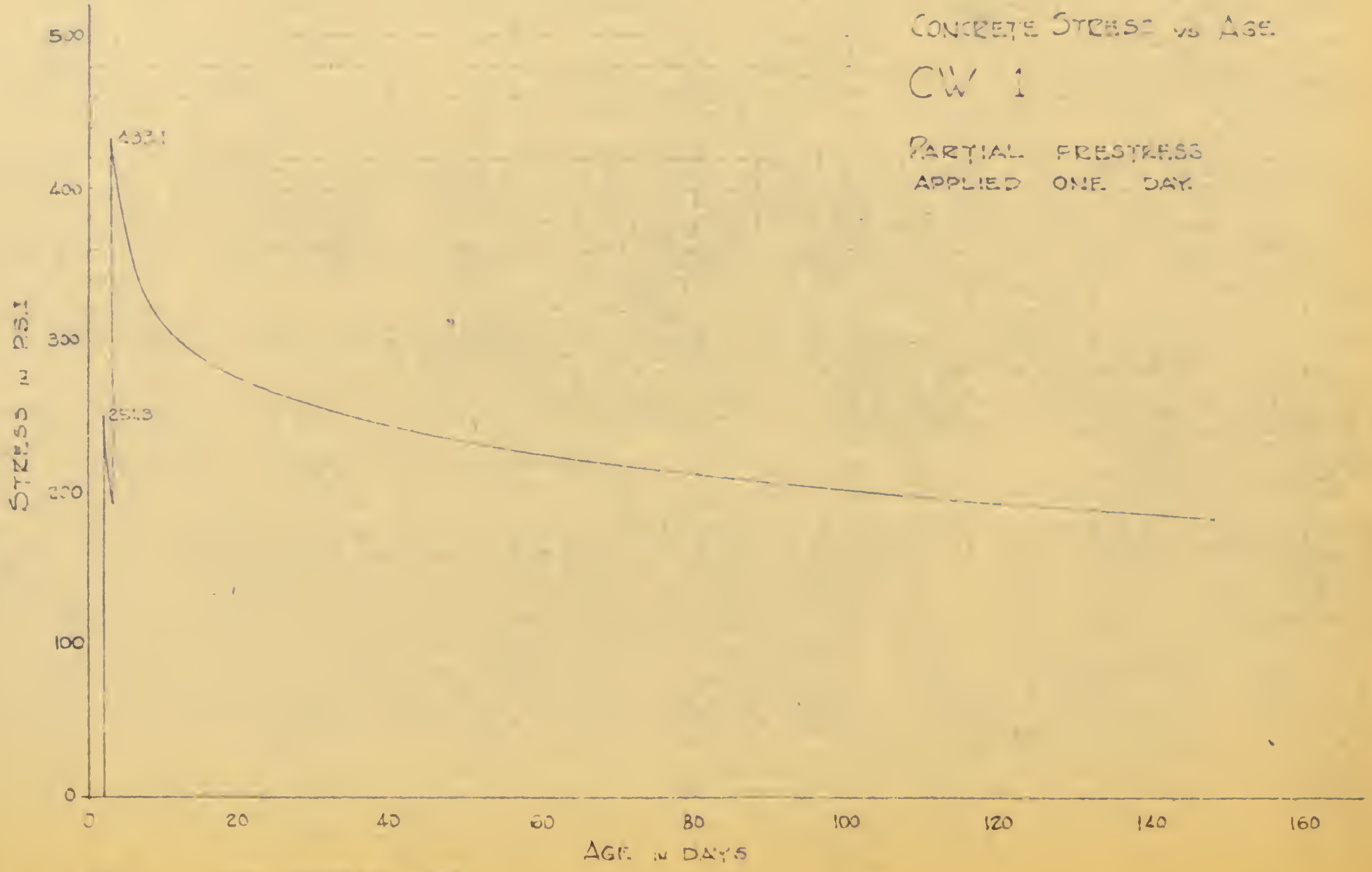


FIG. 6. CW 1 STRESS LOSS.

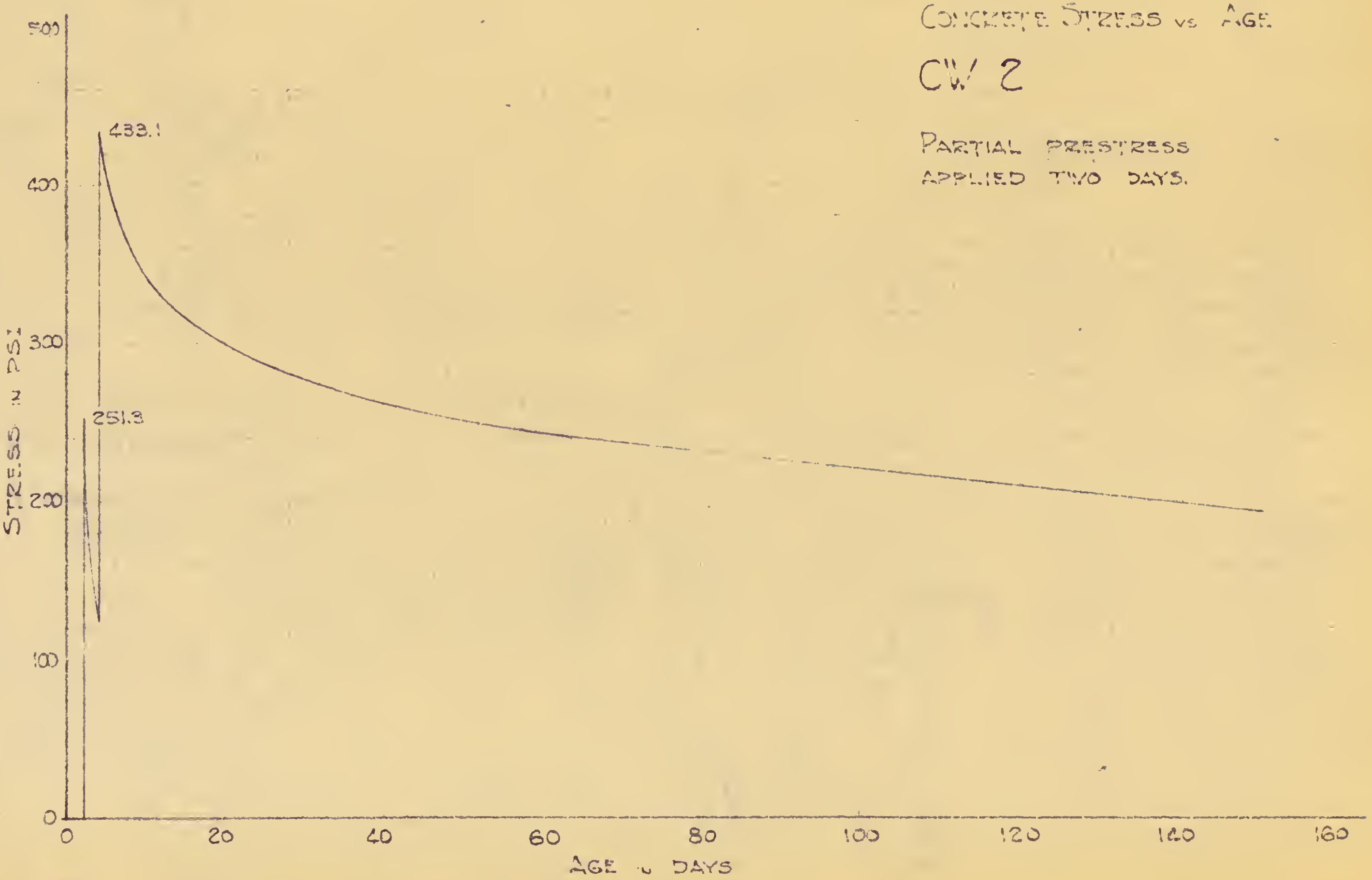
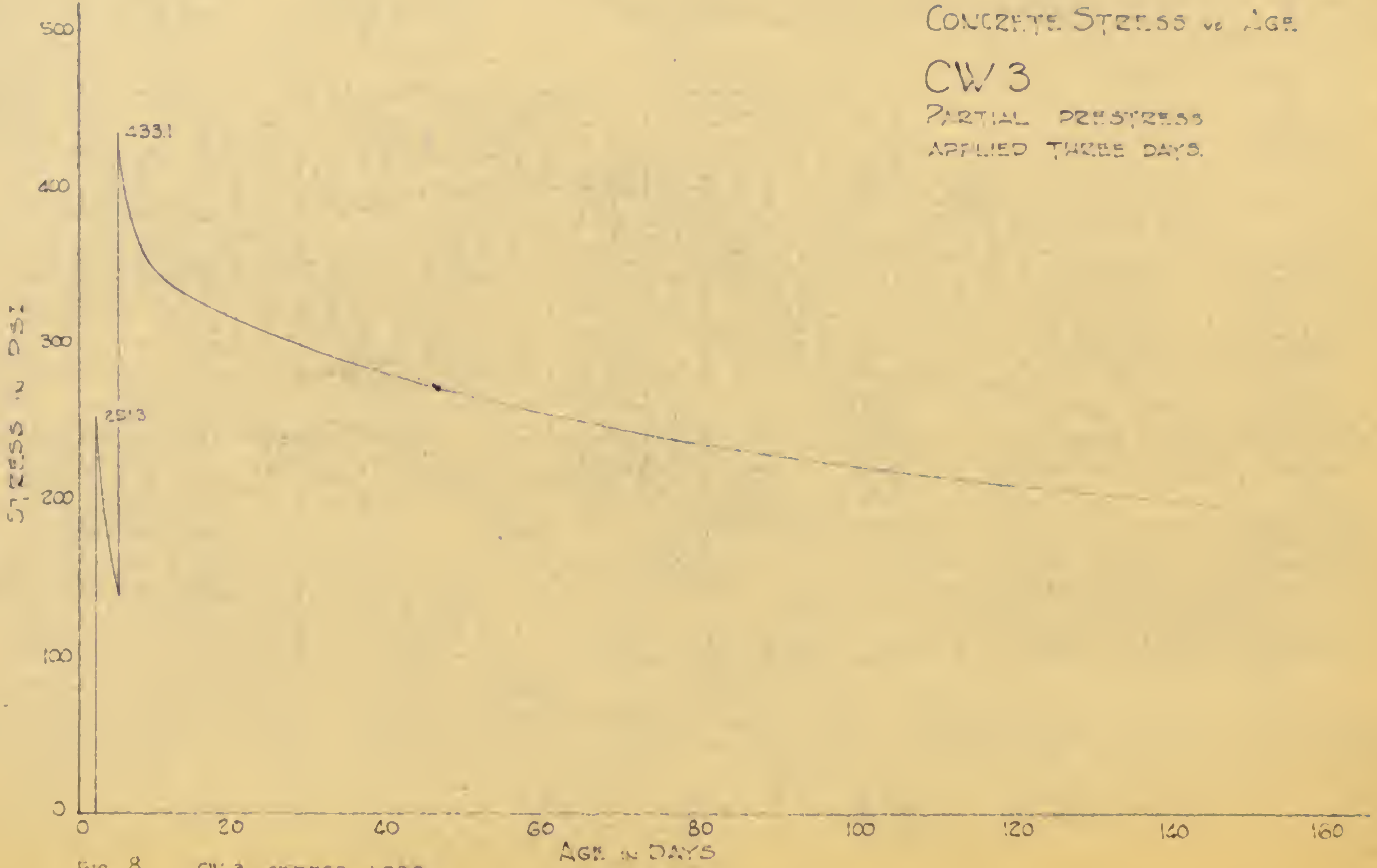


FIG. 7. CW 2 STRESS LOSS.



CONCRETE STRESS vs AGE

CW 3

PARTIAL PRESTRESS
APPLIED THREE DAYS.

FIG 8. CW 3 STRESS LOSS.

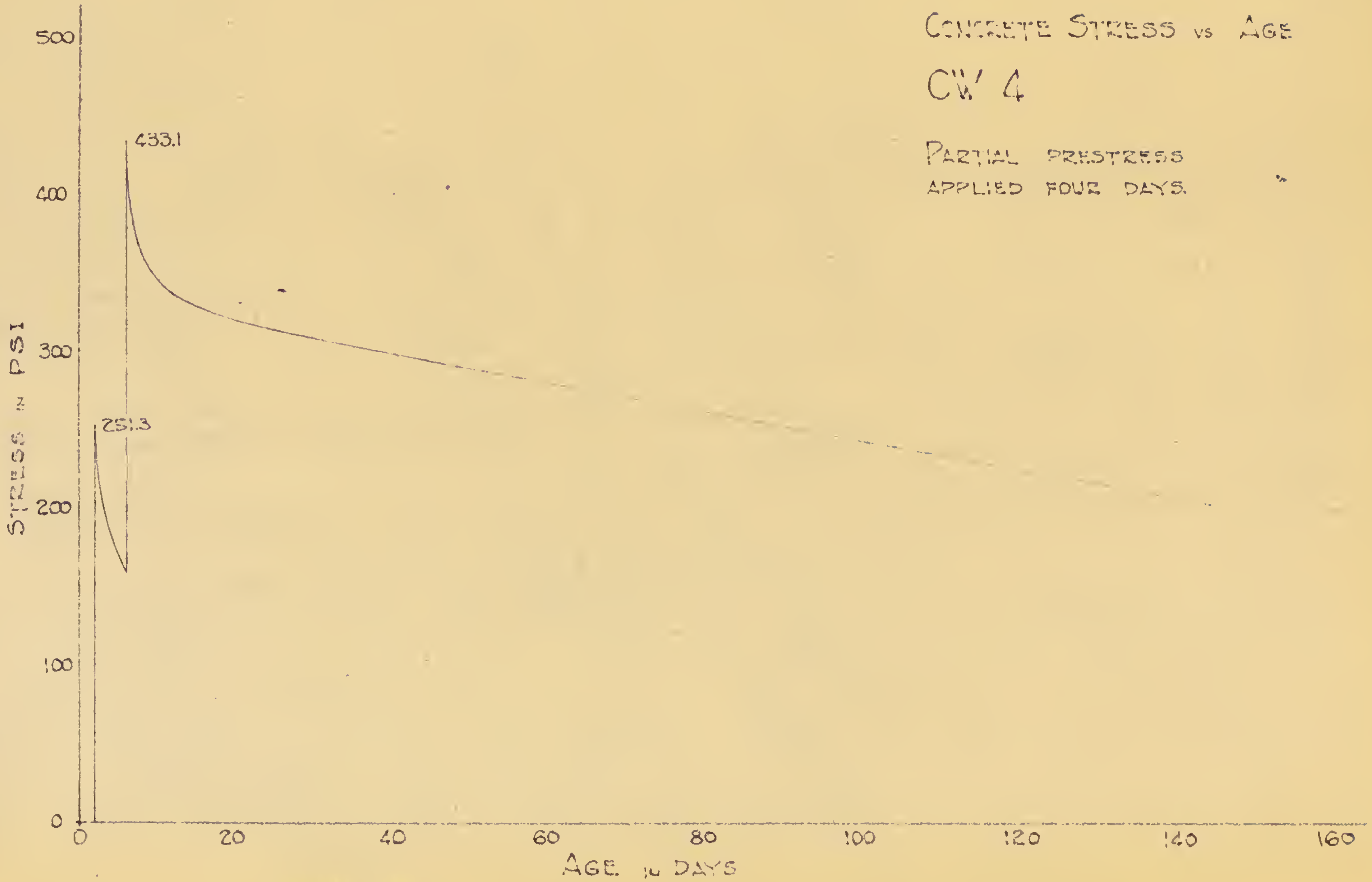


FIG. 9. CW 4 STRESS LOSS.

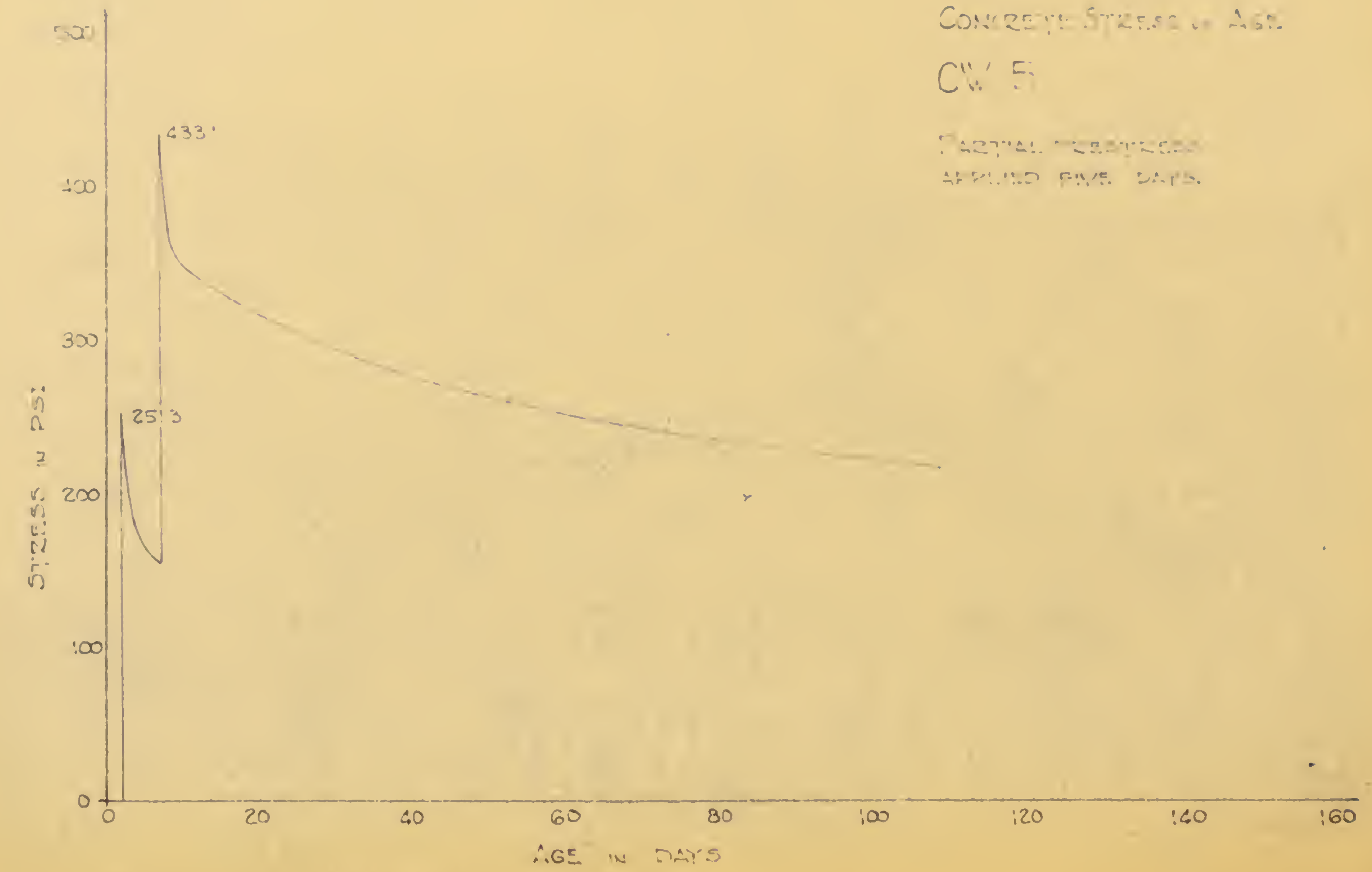


FIG 10. CW 5 STRESS LOSS.

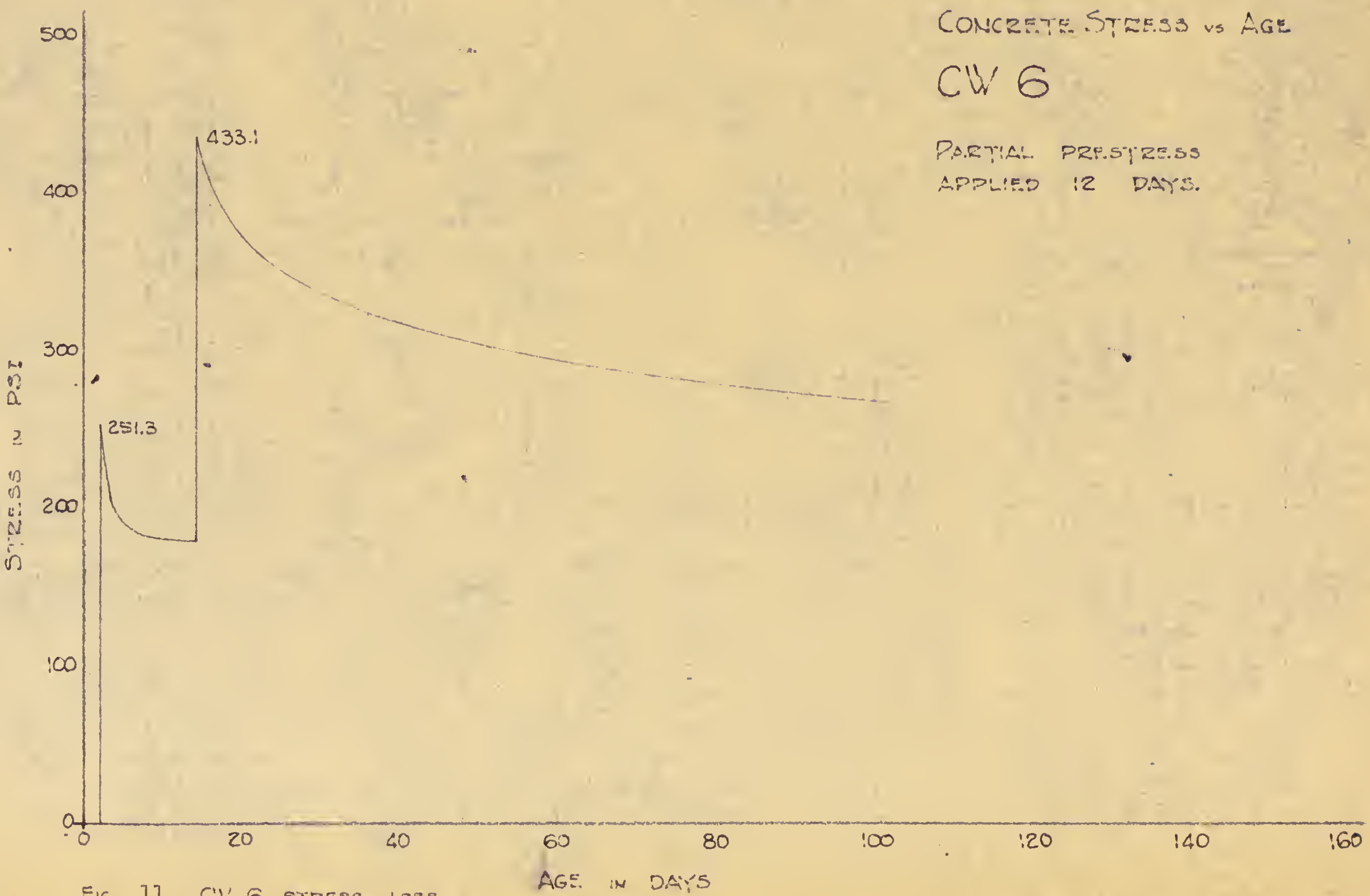


FIG 11. CW 6 STRESS LOSS.

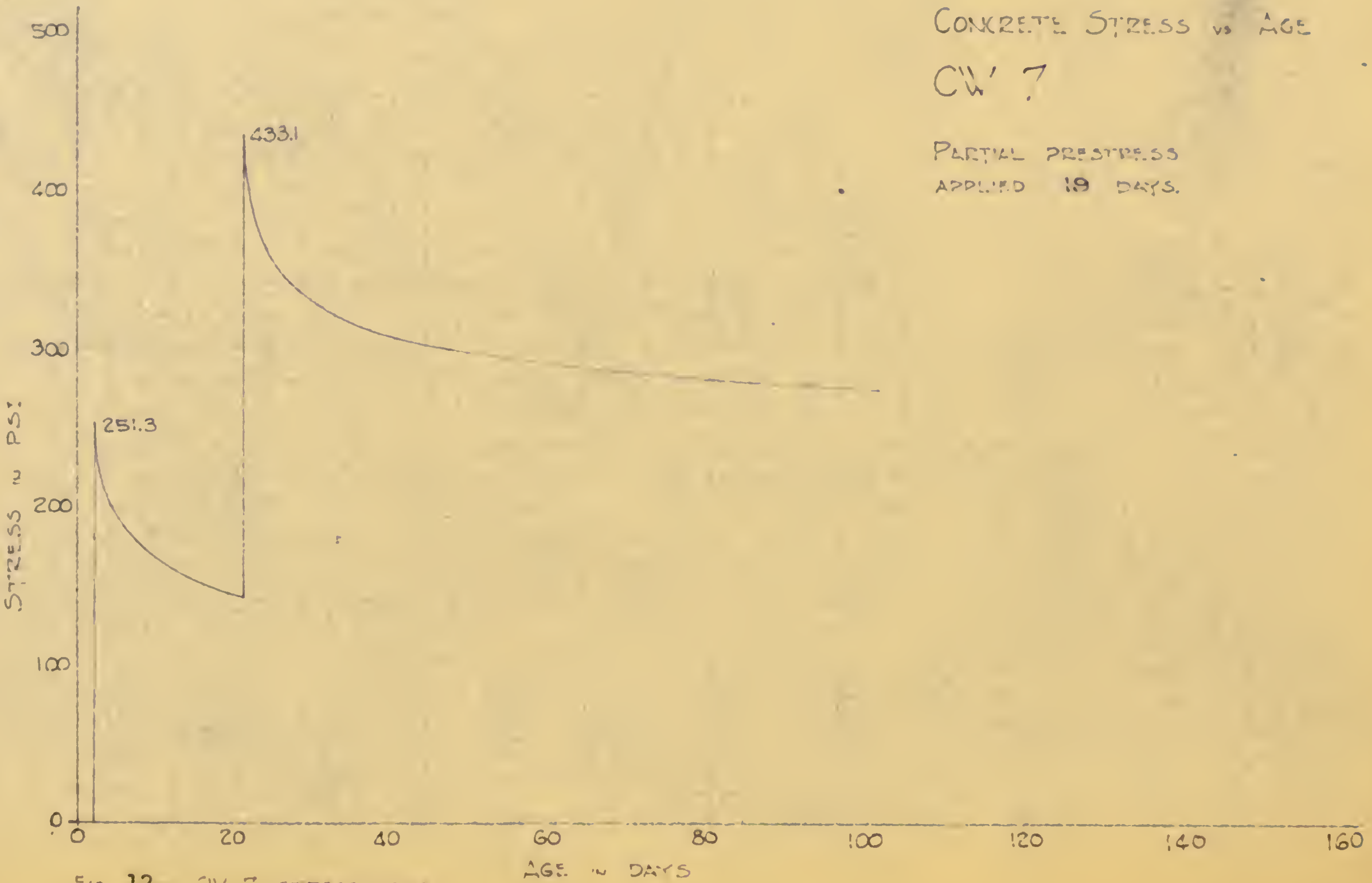


FIG **12.** CW 7 STRESS LOSS.

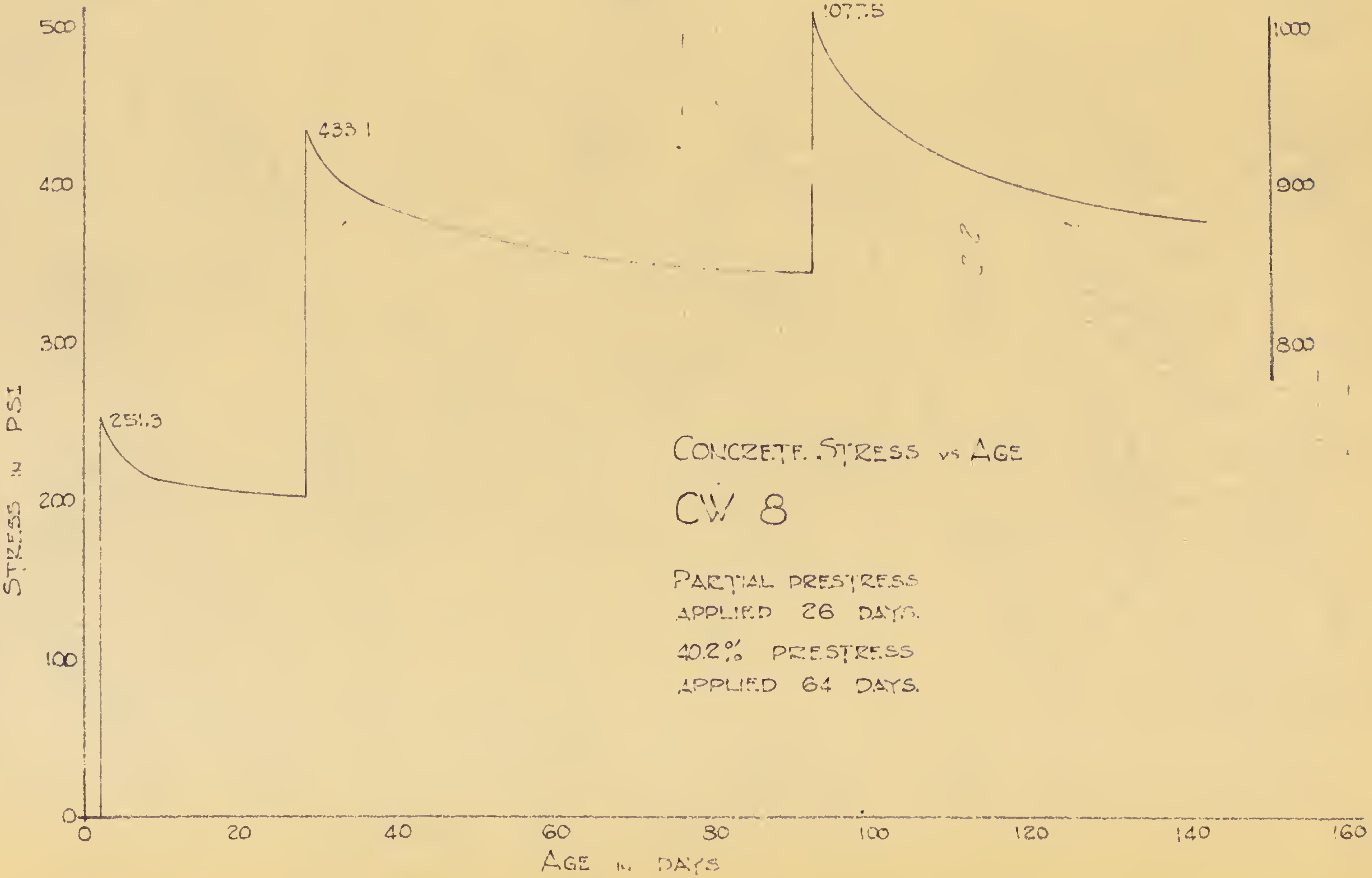


Fig. 13. CW 8 stress loss.

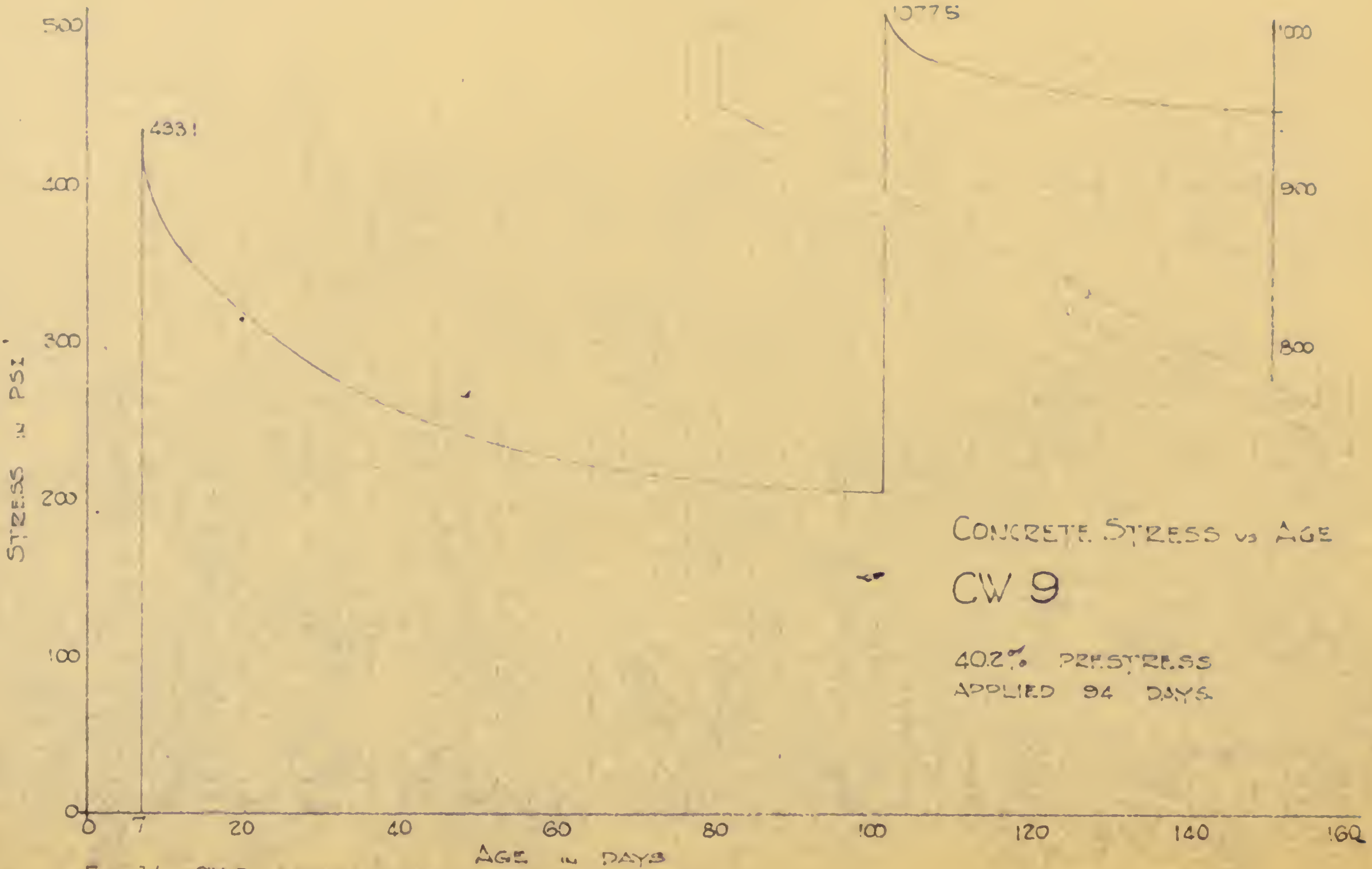


FIG 14. CW 9 STRESS LOSS.

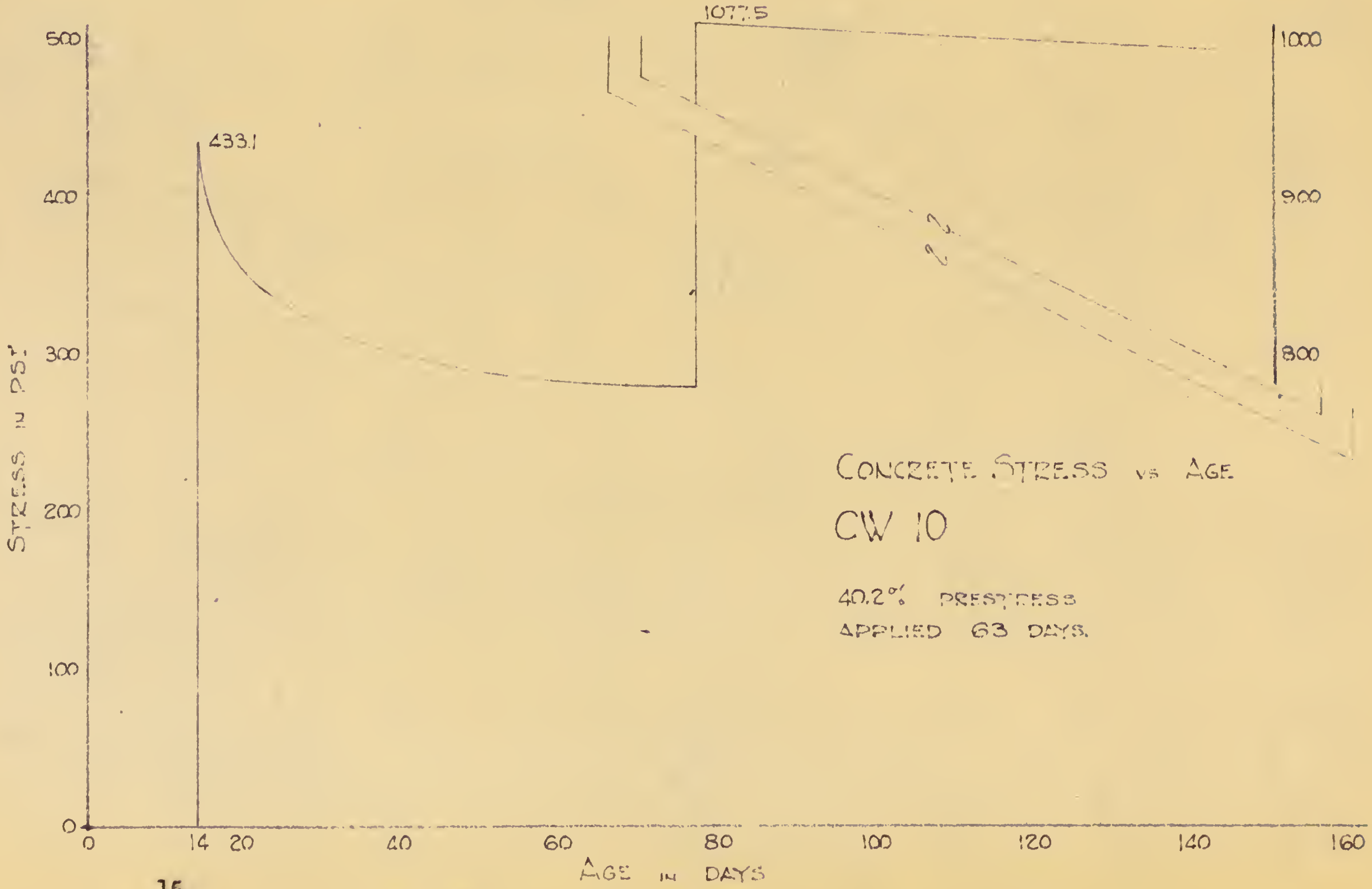


FIG. **15.** CW 10 STRESS LOSS.

Table 7. CW 1 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
29 Sept.,'53	0	-	-	Made
1 Oct.	2	390	251	Partial
2 "	3	300	193	58
	3	672	433	Full PS
3 "	4	570	371	62
5 "	6	570	371	62
6 "	7	565	364	69
7 "	8	492	316	117
8 "	9	488	316	117
9 "	10	480	309	124
10 "	11	460	296	137
12 "	13	445	287	146
13 "	14	445	287	146
14 "	15	445	287	146
15 "	16	435	280	153
16 "	17	415	267	165
19 "	20	415	267	165
23 "	24	415	267	165
27 "	28	415	267	165
30 "	31	410	264	169
3 Nov.	35	395	255	178
6 "	38	405	261	172
10 "	42	385	248	185
13 "	45	375	242	191
18 "	50	365	235	198
20 "	52	365	235	198
24 "	56	345	222	211
1 Dec.	63	350	226	207
4 "	66	350	226	207
9 "	71	355	229	204
18 "	80	340	220	213
4 Jan.,'54	97	340	220	213
22 "	112	290	187	246
27 "	148	285	184	249

Table 8. CW 2 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
29 Sept.,'53	0	–	–	Made
1 Oct.	2	390	251	Partial
2 "	3	165	106	145
3 "	4	190	122	129
3 "	4	672	433	Full PS
5 "	6	590	380	53
6 "	7	580	377	56
7 "	8	550	354	79
8 "	9	530	342	91
9 "	10	520	335	98
10 "	11	480	309	124
12 "	13	480	309	124
13 "	14	480	309	124
14 "	15	480	309	124
15 "	16	485	313	120
19 "	20	480	309	124
23 "	24	465	300	133
27 "	28	450	290	143
30 "	31	450	290	143
2 Nov.	35	430	277	156
6 "	38	425	274	159
10 "	42	440	284	149
13 "	45	405	261	172
18 "	50	385	248	185
20 "	52	400	258	175
24 "	56	380	245	188
1 Dec.	63	380	245	188
4 "	66	360	232	201
9 "	71	365	235	198
18 "	80	355	229	204
4 Jan.,'54	97	355	229	204
22 "	115	335	216	217
27 Feb.	151	295	190	243

Table 9. CW 3 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
5 Oct.,'53	0	--	-	Made
7 "	2	390	251	Partial
8 "	3	280	180	71
9 "	4	250	161	90
10 "	5	672	433	Full PS
12 "	7	640	412	21
13 "	8	540	348	85
14 "	9	545	351	82
15 "	10	525	338	95
16 "	11	520	335	98
19 "	14	500	322	111
20 "	15	500	322	111
21 "	16	490	316	117
22 "	17	490	316	117
23 "	18	510	329	104
26 "	21	490	316	117
28 "	23	485	312	121
30 "	25	480	309	124
2 Nov.	28	460	296	137
6 "	32	455	293	140
10 "	36	450	290	143
13 "	39	450	290	143
18 "	44	420	271	162
20 "	46	440	284	149
24 "	50	410	264	169
1 Dec.	57	415	267	166
4 "	60	400	258	175
9 "	65	410	264	169
18 "	74	410	264	169
4 Jan.,'54	91	385	248	185
22 "	109	365	235	198
27 Feb.	145	295	190	253

Table 10. CW 4 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
6 Oct.,'53	0	–	–	Made
8 "	2	390	251	Partial
9 "	3	310	200	51
10 "	4	280	180	71
12 "	6	250	161	90
12 "	6	672	433	Full PS
13 "	7	570	367	66
14 "	8	550	354	79
15 "	9	545	351	82
16 "	10	530	342	91
19 "	13	540	348	85
20 "	14	530	342	91
21 "	15	520	335	98
22 "	16	510	329	104
23 "	17	510	329	104
26 "	20	505	325	108
27 "	21	505	325	108
28 "	22	505	325	108
30 "	24	490	316	117
2 Nov.	27	490	316	117
4 "	29	490	316	117
6 "	31	475	306	127
10 "	35	490	316	117
13 "	38	470	303	130
18 "	43	455	293	140
20 "	45	450	290	143
24 "	49	450	290	143
1 Dec.	56	440	284	149
4 "	59	430	277	156
9 "	64	430	277	156
18 "	73	430	277	156
4 Jan.,'54	90	420	271	162
22 "	108	360	232	201
27 Feb.	144	305	197	236

Table 11. CW 5 stresses, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
6 Oct.,'53	0	-	-	Made
8 "	2	390	251	Partial
9 "	3	290	186	65
10 "	4	280	180	71
12 "	6	250	161	90
13 "	7	255	164	87
13 "	7	672	433	Full PS
14 "	8	540	348	85
15 "	9	535	345	88
16 "	10	540	348	85
19 "	13	510	329	104
20 "	14	520	335	98
21 "	15	510	329	104
22 "	16	510	329	104
23 "	17	510	329	104
26 "	20	500	322	111
27 "	21	495	319	114
28 "	22	480	309	124
30 "	24	480	309	124
2 Nov.	27	485	313	120
4 "	29	475	306	127
6 "	31	440	284	149
10 "	35	460	296	137
13 "	38	405	261	173
18 "	43	425	274	159
20 "	45	400	258	175
24 "	49	410	264	169
1 Dec.	56	410	264	169
4 "	59	420	271	162
9 "	64	390	251	182
18 "	73	380	245	188
4 Jan.,'54	90	380	245	188
22 "	108	335	216	217
22 "	(Wire failed with full 1078 prestress attempt)			

Table 12. CW 6 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
12 Oct.,'53	0	-	-	Made
14 "	2	390	251	Partial
15 "	3	320	206	45
16 "	4	300	193	58
19 "	7	280	180	71
21 "	9	280	180	71
23 "	11	275	177	74
26 "	14	275	177	74
26 "	14	672	433	Full PS
27 "	15	630	406	27
28 "	16	630	406	27
29 "	17	610	393	40
30 "	18	600	387	46
2 Nov.	21	605	390	43
3 "	22	560	361	72
4 "	23	570	367	66
5 "	24	535	345	88
6 "	25	550	354	79
9 "	28	510	329	104
10 "	29	500	322	111
11 "	30	500	322	111
13 "	32	500	322	111
16 "	35	500	322	111
18 "	37	505	325	108
20 "	39	500	322	111
23 "	42	490	316	117
30 "	49	490	316	117
3 Dec.	52	490	316	117
7 "	56	470	303	130
10 "	59	470	303	130
17 "	66	470	303	130
5 Jan.,'54	85	425	274	159
22 "	102	420	271	162
22 "	(Wire failed with full 1078 prestress attempt)			

Table 13. CW 7 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
13 Oct.,'53	0	-	-	Made
15 "	2	390	251	Partial
16 "	3	325	209	42
19 "	6	290	187	65
21 "	8	270	174	77
23 "	10	270	174	77
26 "	13	265	171	80
29 "	16	240	155	96
2 Nov.	20	240	155	96
3 "	21	220	142	109
3 "	21	672	433	Full PS
4 "	22	575	371	62
5 "	23	545	351	82
6 "	24	545	351	82
9 "	27	520	335	98
10 "	28	550	354	79
11 "	29	540	348	85
12 "	30	540	348	85
13 "	31	505	325	108
16 "	34	510	329	104
18 "	36	485	313	120
19 "	37	490	316	117
20 "	38	495	319	114
23 "	41	480	309	124
30 "	48	470	303	130
3 Dec.	51	460	296	137
7 "	55	450	290	143
10 "	58	460	296	137
17 "	65	460	296	137
5 Jan.,'54	84	450	290	143
22 "	101	420	270	163
22 "	(Three wires failed with full 1078 prestress attempt)			

Table 14. CW 8 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
22 Oct.,'53	0	-	-	Made
24 "	2	390	251	Partial
26 "	4	350	225	26
27 "	5	350	225	26
29 "	7	345	222	29
2 Nov.	11	325	209	42
6 "	15	330	213	38
9 "	18	330	213	38
12 "	21	320	206	45
16 "	25	310	200	51
19 "	28	320	206	45
19 "	28	672	433	Full PS
20 "	29	630	406	27
21 "	30	610	393	40
23 "	32	610	393	40
24 "	33	635	409	24
30 "	39	585	377	56
1 Dec.	40	620	390	43
2 "	41	615	396	37
3 "	42	610	393	40
7 "	46	585	377	56
9 "	48	580	374	59
10 "	49	580	374	59
17 "	56	570	367	66
5 Jan.,'54	75	540	348	85
22 "	92	535	345	88
22 "	92	1672	1078	Full PS
13 March	142	1360	876	202

Table 15. CW 9 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
13 Oct.,'53	0	-	-	Made
20 "	7	672	433	Full PS
21 "	8	600	387	46
22 "	9	560	361	72
23 "	10	560	361	72
26 "	13	560	361	72
27 "	14	550	354	79
28 "	15	535	345	88
29 "	16	525	338	95
30 "	17	515	332	101
2 Nov.	20	490	316	117
3 "	21	490	316	117
4 "	22	480	309	124
6 "	24	470	303	130
9 "	27	470	303	130
11 "	29	440	284	149
13 "	31	450	290	143
16 "	34	410	264	169
18 "	36	400	258	175
21 "	39	380	245	188
24 "	42	345	222	211
30 "	48	360	232	201
3 Dec.	51	350	226	207
7 "	55	360	232	201
10 "	58	350	226	207
17 "	65	335	216	217
5 Jan.,'54	84	325	209	224
22 "	101	1672	1078	Full PS
13 March	151	1470	947	131

Table 16. CW 10 stress, stress loss and age.

Date	Age in Days	Jack Rod Strain 10^{-6} in/in.	Concrete Stress psi	Total Stress Loss psi
22 Oct.,'53	0	-	-	Made
4 Nov.	14	672	433	Full PS
6 "	15	590	380	53
9 "	18	575	371	62
10 "	19	570	367	66
11 "	20	550	354	79
12 "	21	540	348	85
13 "	22	520	335	98
16 "	25	510	329	104
18 "	27	500	322	111
19 "	28	500	322	111
20 "	29	465	300	133
23 "	32	475	306	127
30 "	39	470	303	130
3 Dec.	42	470	303	130
7 "	46	470	303	130
10 "	49	455	293	140
17 "	56	435	280	153
5 Jan.,'54	75	430	277	156
7 "	77	1672	1078	Full PS
22 "	92	1620	1044	34
13 March	142	1540	992	86

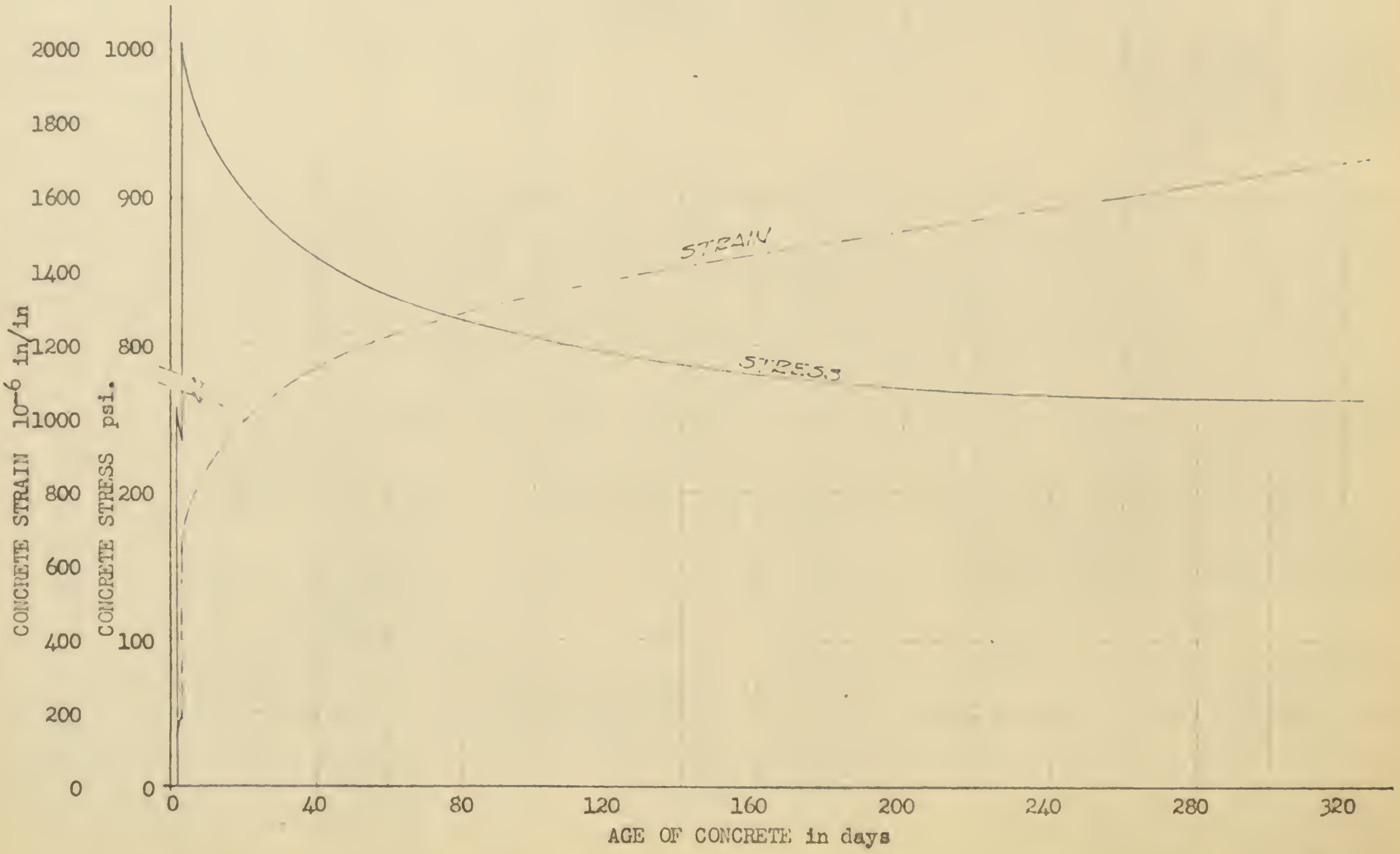


Fig 16. Concrete stress and concrete strain of CW 1.

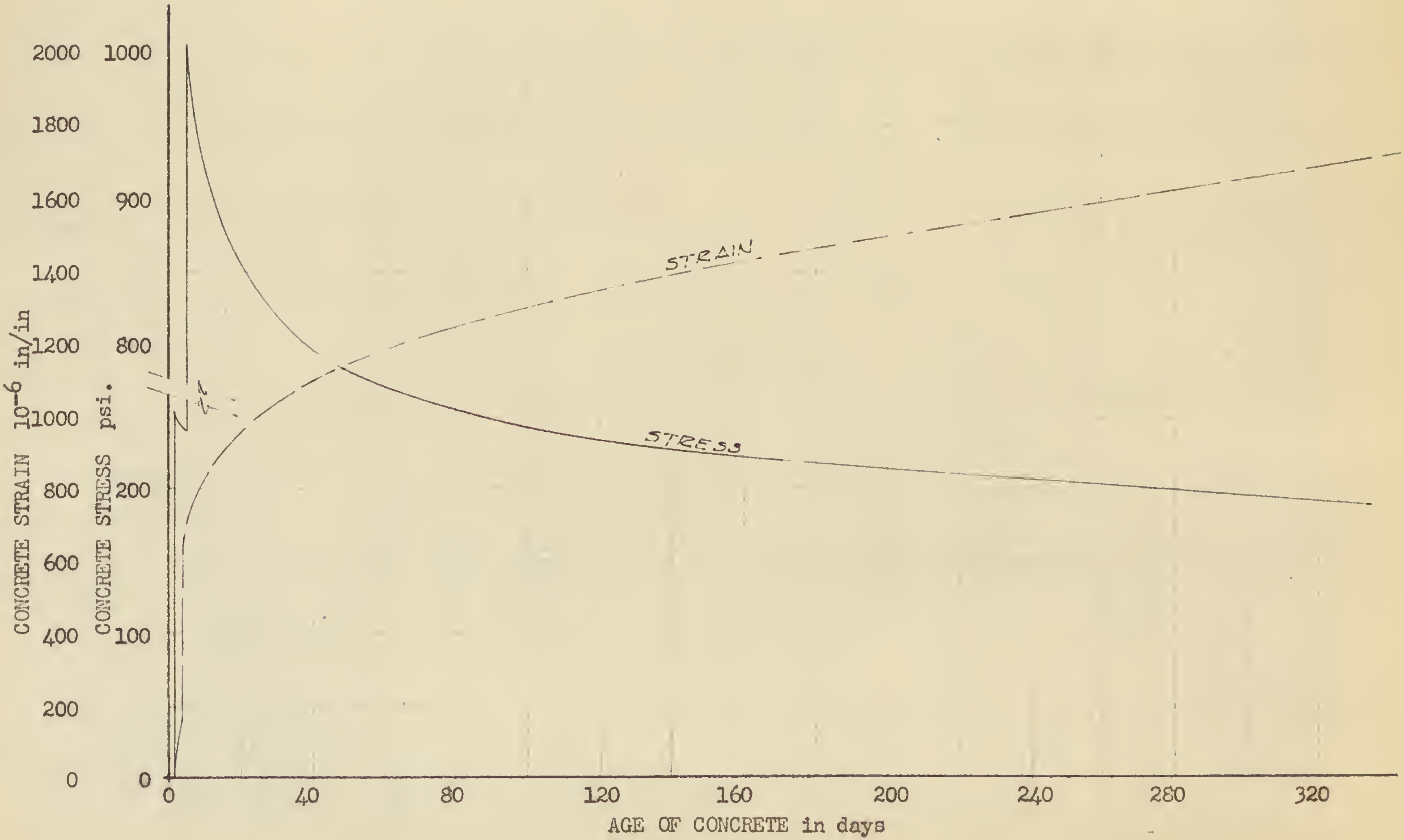


Fig 17. Concrete stress and concrete strain of CW 2.

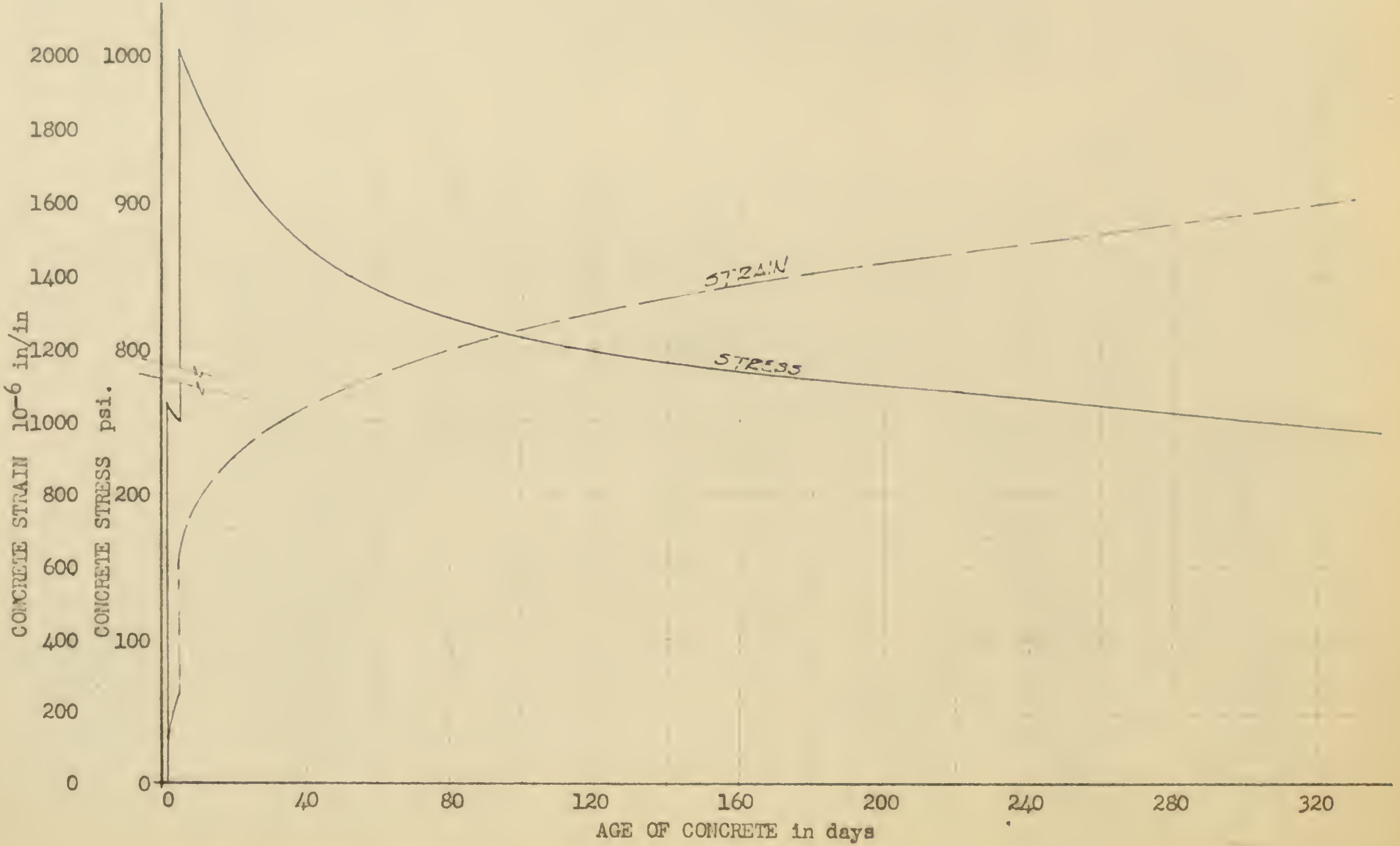


Fig 18 • Concrete stress and concrete strain of CW 3.

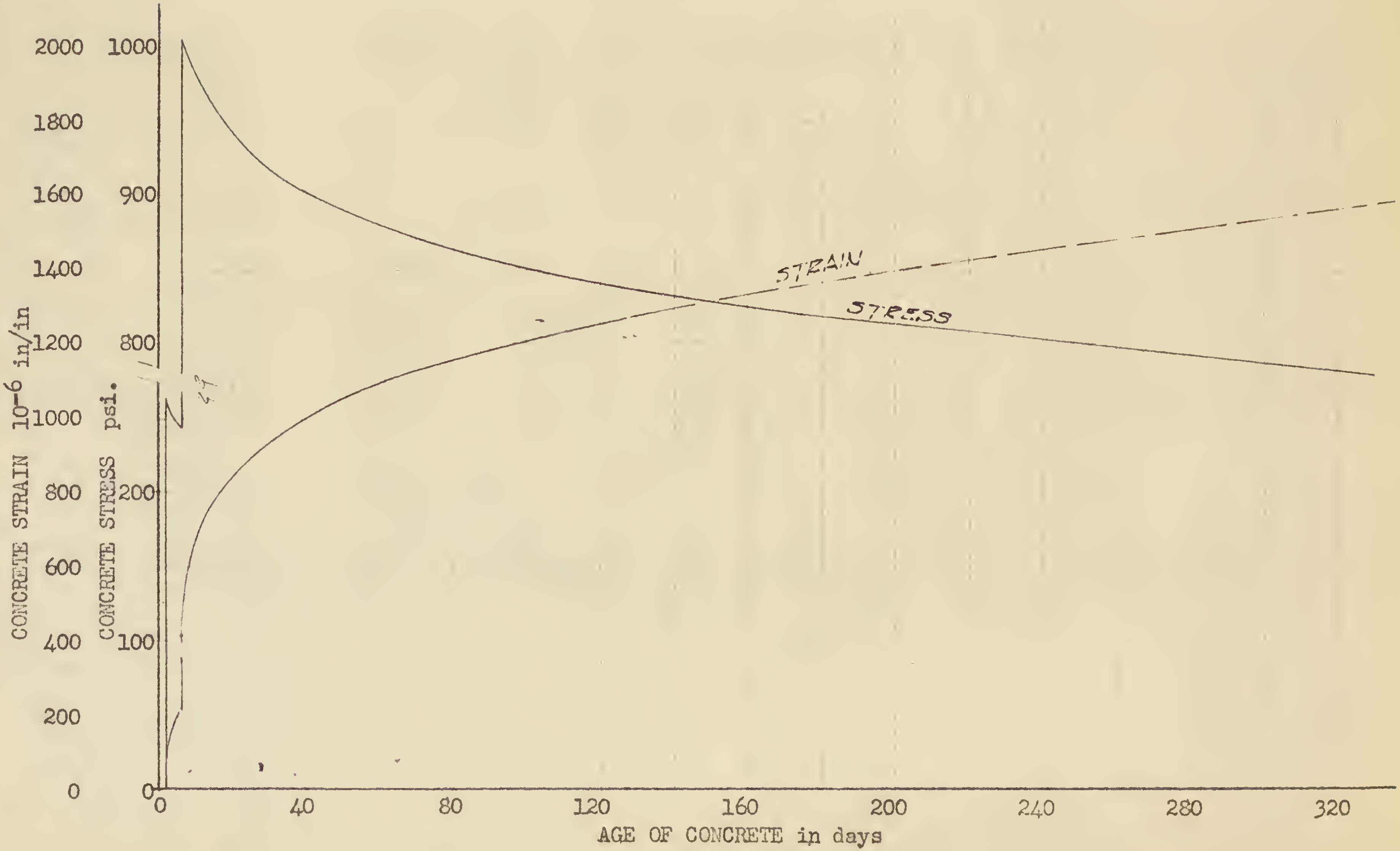


Fig 19. Concrete stress and concrete strain of CW 4.

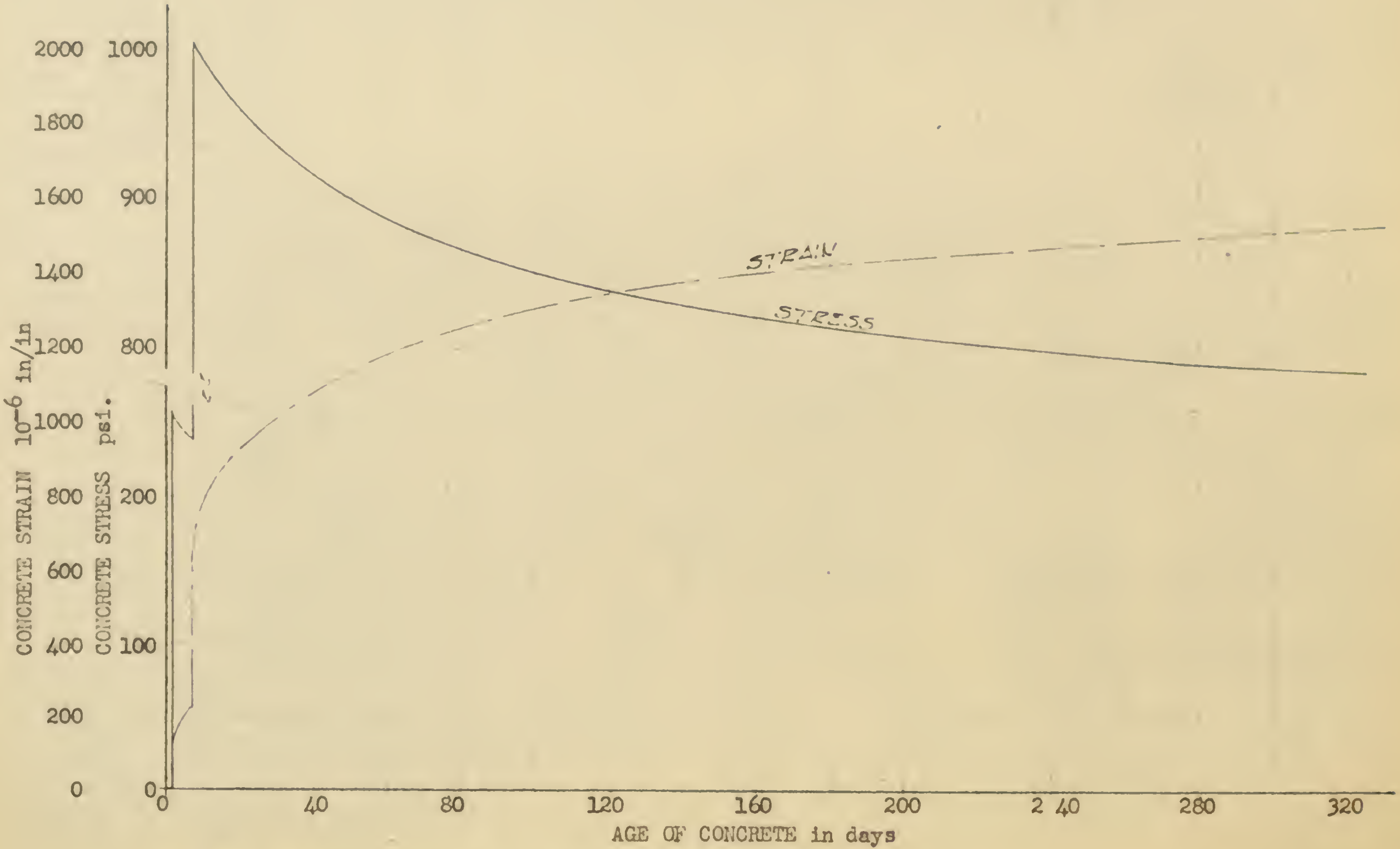


Fig 20. Concrete stress and concrete strain of CW 5.

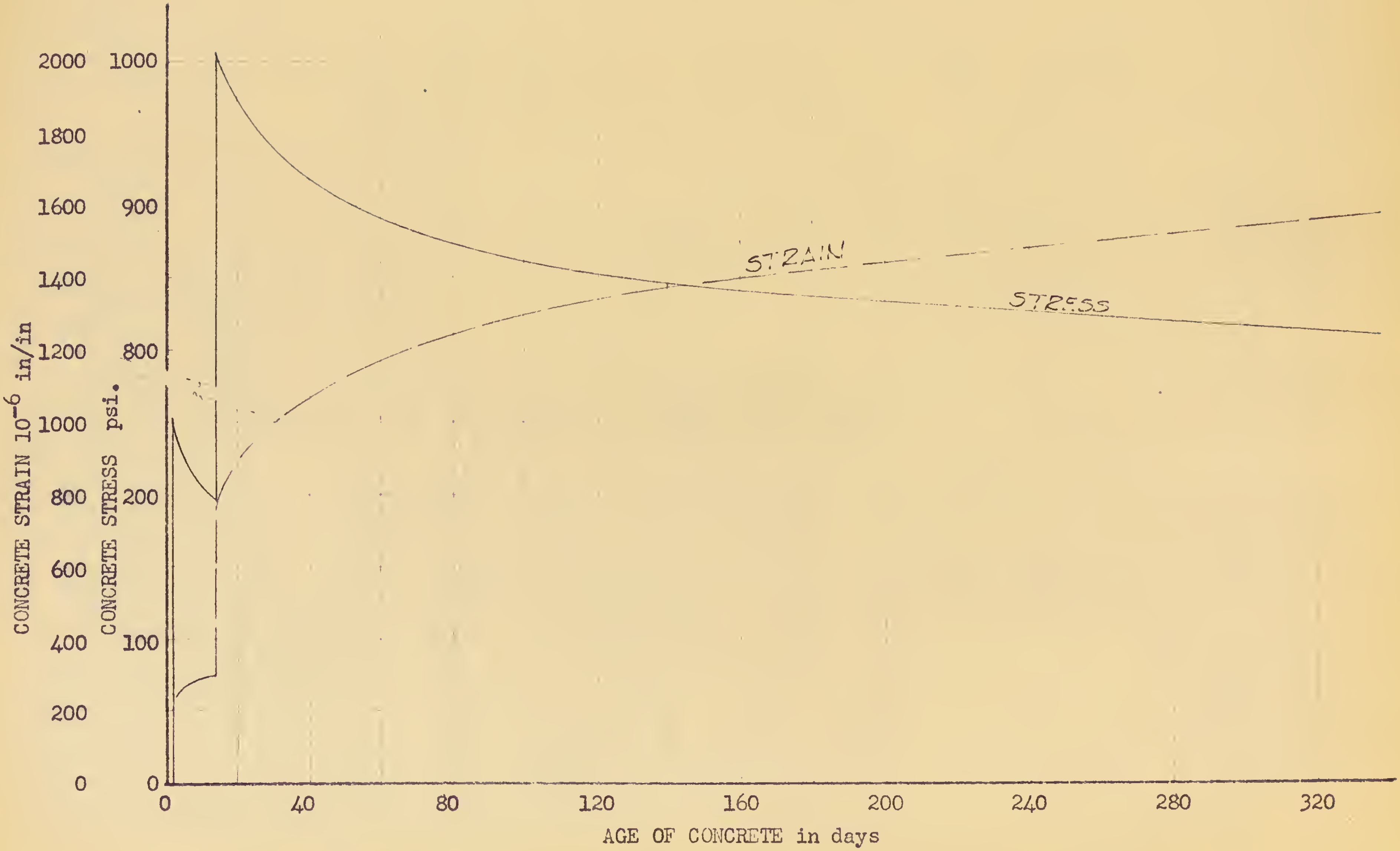


Fig. 21. Concrete stress and concrete strain of CW 6.

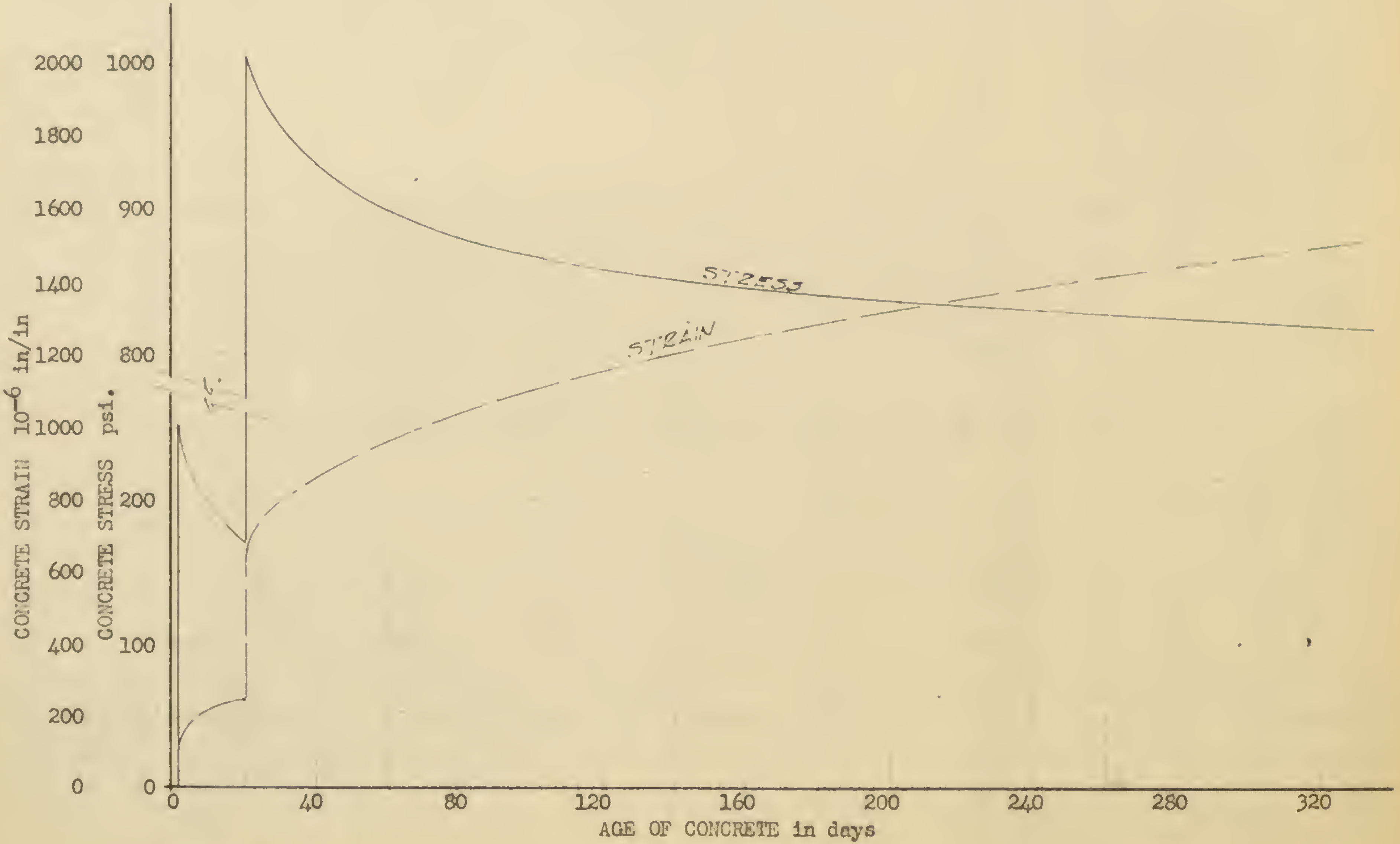


Fig 22. Concrete stress and concrete strain of CW 7.

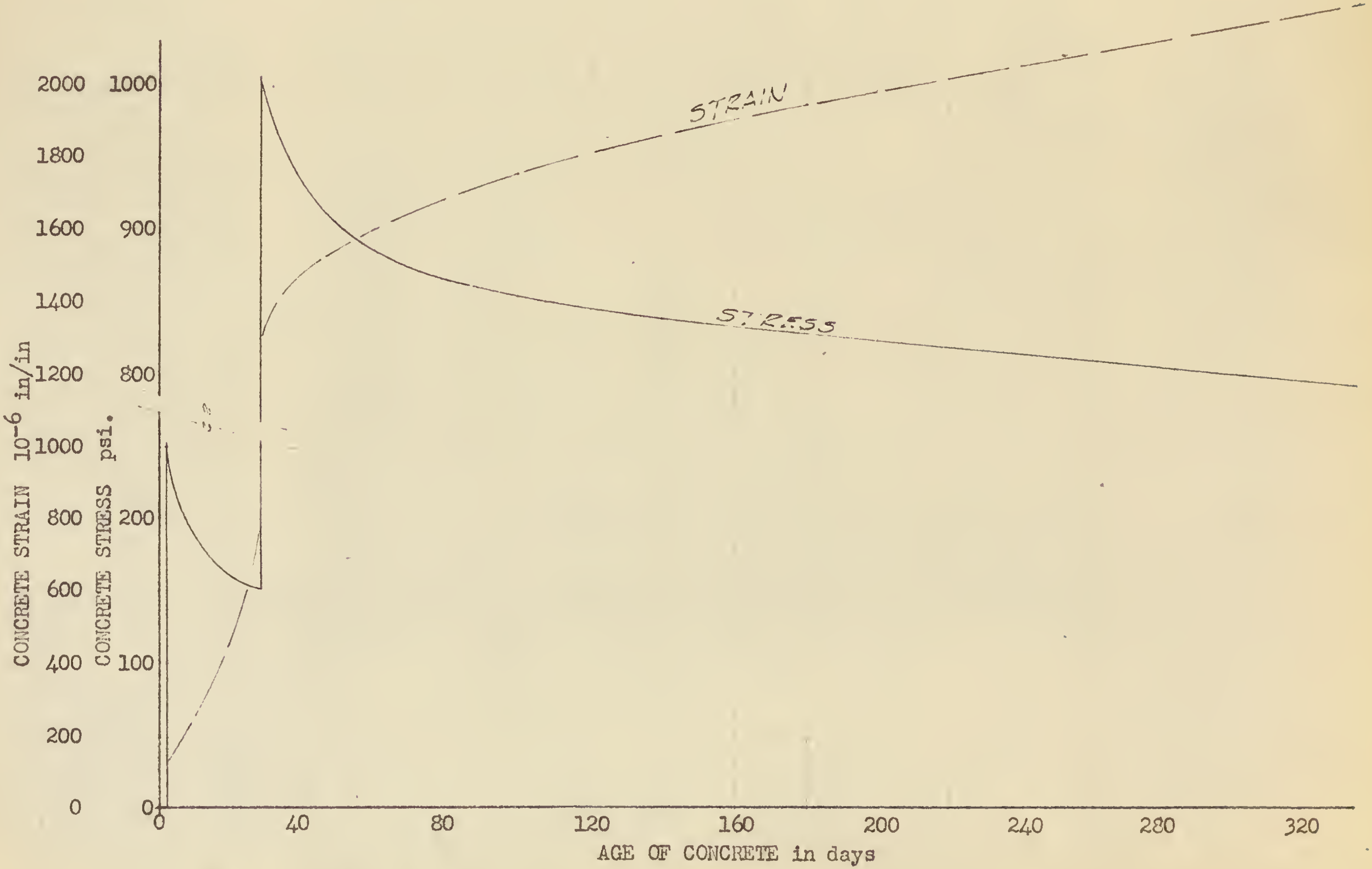


Fig 23. Concrete stress and concrete strain of CW 8.

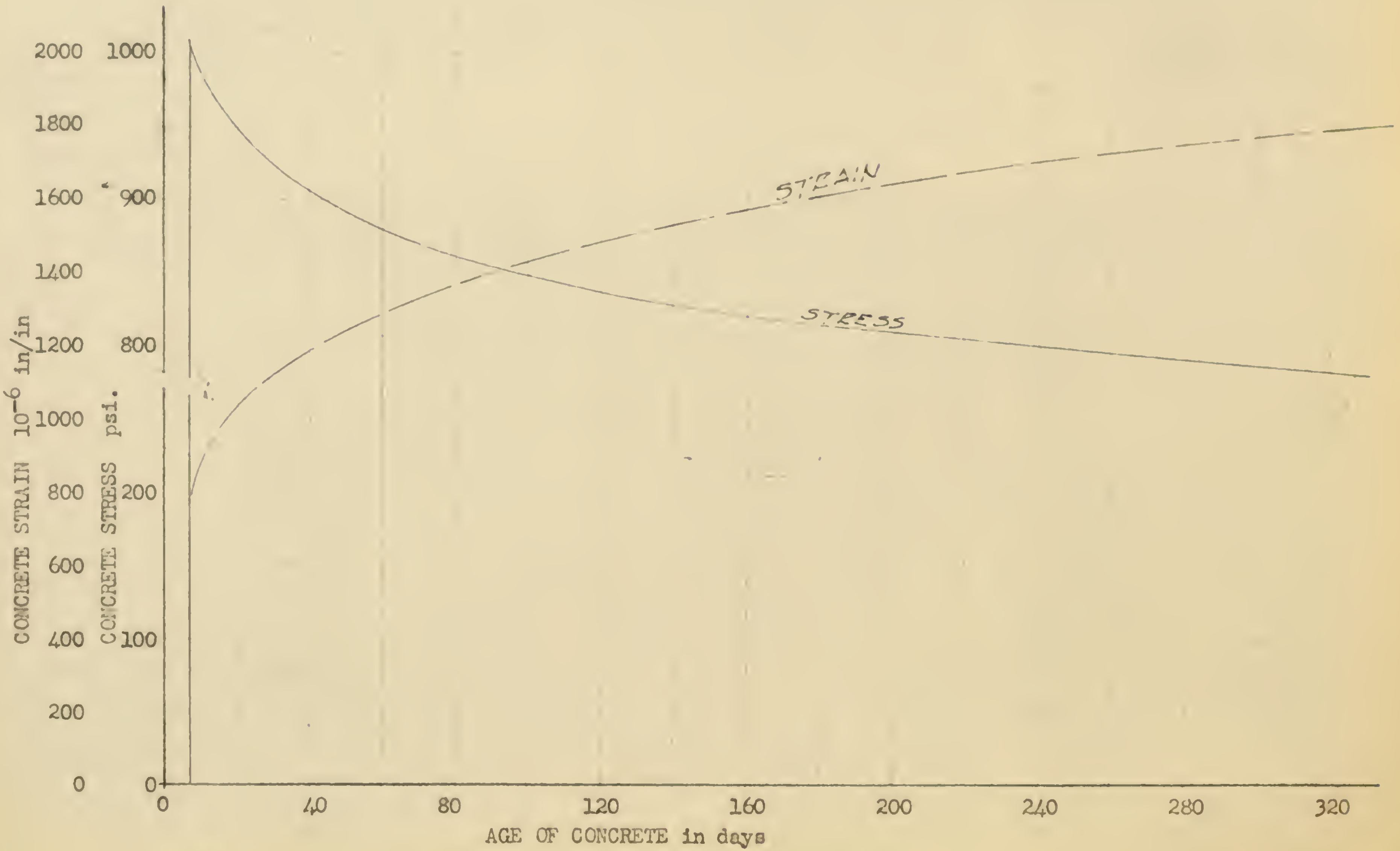


Fig 24 . Concrete stress and concrete strain of CW 9.

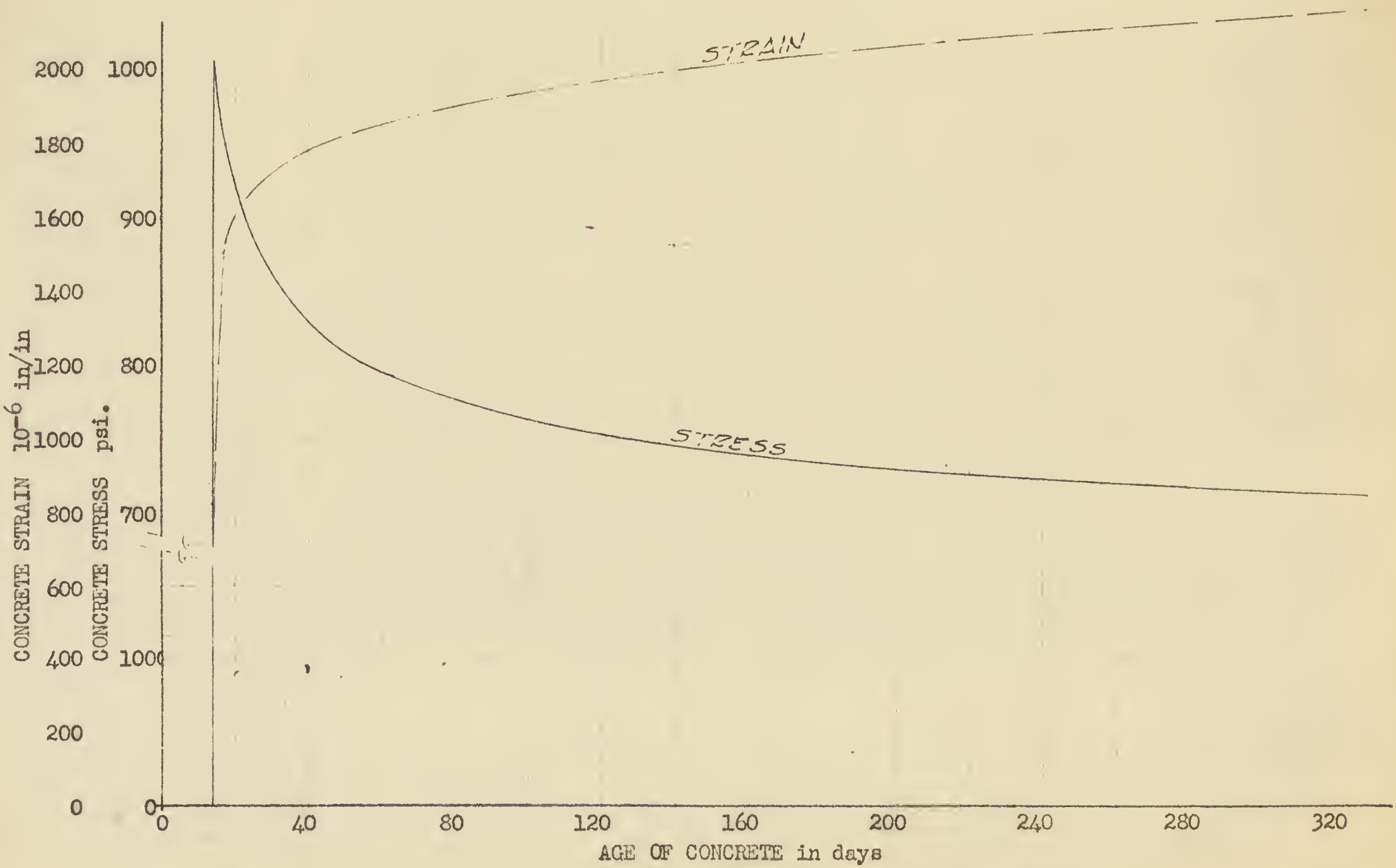


Fig 25. Concrete stress and concrete strain of CW 10.

Table 17. CW 1 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
27 Feb.,'54	0	---	-	Made
1 March	2	1450	260	Partial
2 "	3	6000	1070	Full PS
5 "	6	5700	1017	53
12 "	13	5150	922	148
19 "	20	5125	915	155
26 "	27	4975	889	181
9 April	41	4900	875	195
1 May	63	4650	830	240
29 "	91	4450	794	276
29 June	122	4375	782	288
28 July	151	4275	762	308
8 Oct.	223	4300	767	303
26 Nov.	272	4125	736	334
28 Jan.,'55	335	4125	736	334

Table 18. CW 2 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
2 Mar.,'54	0	-	-	Made
4 "	2	1450	260	Partial
6 "	4	6000	1070	Full PS
9 "	7	5250	940	130
23 "	21	5050	903	127
31 "	29	4600	820	250
14 April	43	4425	783	287
28 "	57	4400	781	289
27 May	86	4220	756	314
29 June	118	4125	736	334
28 July	147	4200	751	319
2 Oct.	219	4100	730	340
26 Nov.	268	3875	692	378
28 Jan.,'55	331	3825	682	388

Table 19. CW 3 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
13 Mar.,'54	0	-	-	Made
15 "	2	1450	260	Partial
18 "	5	1300	249	11
18 "	5	6030	1078	Full PS
20 "	7	5650	1008	70
27 "	14	5400	966	112
3 April	21	5200	931	147
10 "	28	5150	922	156
23 "	41	4800	857	221
6 May	54	4800	857	221
29 "	77	4650	830	248
29 June	108	4525	806	272
28 July	137	4500	802	276
8 Oct.	209	4400	781	297
26 Nov.	258	4225	756	322
28 Jan.,'55	321	4200	751	327

Table 20. CW 4 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
9 Mar.,'54	0	-	-	Made
11 "	2	1450	260	Partial
15 "	6	1250	244	16
15 "	6	6030	1078	Full PS
17 "	8	5500	982	96
24 "	15	5450	975	103
31 "	23	5200	931	147
7 April	30	5150	922	156
21 "	44	5100	911	167
5 May	58	4975	889	189
27 "	80	4900	875	203
29 June	112	4725	840	238
28 July	141	4725	840	238
8 Oct.	213	4500	802	276
26 Nov.	262	4450	794	284
28 Jan.,'55	325	4375	782	296

Table 21. CW 5 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
10 Mar., '54	0	-	-	Made
12 "	2	1450	260	Partial
17 "	7	1200	237	23
17 "	7	6030	1078	Full PS
20 "	10	5600	1000	78
27 "	17	5450	975	103
3 April	24	5300	949	129
10 "	31	5250	940	138
23 "	44	5150	922	156
6 May	57	4975	889	189
29 "	80	4800	857	221
29 June	111	4800	857	221
28 July	140	4700	838	240
8 Oct.	212	4700	838	240
26 Nov.	261	4475	799	279
28 Jan., '55	324	4475	799	279

Table 22. CW 6 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
4 Mar.,'54	0	-	-	Made
6 "	2	1450	260	Partial
18 "	14	1000	189	71
18 "	14	6030	1078	Full PS
20 "	16	5700	1017	61
26 "	22	5400	966	112
2 April	29	5300	949	129
9 "	36	5150	922	156
15 "	42	5150	922	156
1 May	58	5000	894	184
22 "	79	4925	880	198
29 June	117	4825	861	217
28 July	146	4725	840	238
8 Oct.	218	4675	833	245
26 Nov.	267	4575	814	264
28 Jan.,'55	330	4575	814	264

Table 23. CW 7 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
11 Mar.,'54	0	-	-	Made
13 "	2	1450	260	Partial
20 "	9	1150	230	30
1 April	21	950	140	90
1 "	21	6030	1078	Full PS
3 "	23	5650	1008	70
10 "	30	5300	949	129
21 "	41	5100	911	167
28 "	48	5075	907	171
11 May	61	5100	911	167
27 "	77	5050	903	175
29 June	110	4900	875	203
28 July	139	4775	851	227
8 Oct.	211	4700	838	240
26 Nov.	260	4625	823	255
28 Jan.,'55	323	4600	820	258

Table 24. CW 8 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
3 Mar.,'54	0	-	-	Made
5 "	2	1450	260	Partial
12 "	9	1000	190	70
19 "	16	950	181	79
31 "	28	750	142	118
31 "	28	6000	1070	Full PS
2 April	30	5450	975	95
9 "	37	5150	922	148
15 "	43	5150	922	148
23 "	51	5050	903	167
5 May	63	4950	884	186
29 "	88	4800	857	213
29 June	118	4800	857	213
28 July	147	4700	838	232
8 Oct.	219	4600	820	250
26 Nov.	268	4500	802	268
28 Jan.,'55	331	4475	799	271

Table 25. CW 9 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
6 Mar.,'54	0	-	-	Made
13 "	7	6030	1078	Full PS
15 "	9	5750	1028	50
23 "	17	5750	1028	50
31 "	25	5200	931	147
6 April	31	5200	931	147
21 "	46	6025	897	181
5 May	50	4925	880	198
27 "	82	4750	848	230
29 June	115	4725	840	238
28 July	144	4625	823	255
8 Oct.	216	4550	812	266
26 Nov.	265	4475	799	279
28 Jan.,'55	328	4425	783	295

Table 26. CW 10 stress, stress loss and age.

Date	Age in Days	Jack Gage Reading	Concrete Stress psi	Total Stress Loss psi
17 Mar.,'54	0	-	-	Made
31 "	14	6000	1070	Full PS
2 April	16	5300	949	121
9 "	23	5000	894	176
15 "	29	4750	848	222
23 "	37	4800	857	213
6 May	50	4800	857	213
29 "	73	4350	778	292
29 June	104	4400	781	289
28 July	133	4200	751	319
8 Oct.	205	4100	730	340
26 Nov.	254	4000	713	357
28 Jan.,'55	317	3950	710	360

Table 27. Average strain in CW 1 (second set).

Date	Age in Days	Berry Gage Reading		Sum Total Dial Change	Average Strain 10^{-6} in/in.
		Left	Right		
27 Feb.,'54	0	-	-	Made	-
1 Mar.	2	0.042	0.047	No Force	-
2 "	3	0.072	0.057	0.040	188(Partial)
2 "	3	0.124	0.102	0.137	646(Final)
5 "	6	0.142	0.112	0.165	778
12 "	13	0.153	0.127	0.191	901
19 "	20	0.165	0.140	0.216	1019
26 "	27	0.167	0.146	0.224	1057
9 April	41	0.182	0.149	0.242	1141
1 May	63	0.195	0.160	0.266	1255
29 "	91	0.160	0.167	0.239	1127
29 June	122	0.206	0.160	0.227	1307
28 July	151	0.213	0.178	0.302	1425
8 Oct.	223	0.224	0.187	0.322	1519
26 Nov.	272	0.240	0.201	0.352	1660
28 Jan.,'55	335	0.245	0.205	0.361	1703

Table 28. Average strain in CW 2.

Date	Age in Days	Berry Gage Reading		Sum Total Dial Change	Average Strain 10^{-6} in/in.
		Left	Right		
2 Mar., '54	0	-	-	Made	-
4 "	2	0.022	0.088	No Force	-
4 "	2	0.033	0.105	0.028	132(Partial)
6 "	4	0.084	0.157	0.131	618(Final)
9 "	7	0.102	0.171	0.163	769
23 "	21	0.120	0.199	0.209	986
31	29	0.120	0.204	0.214	1009
14 April	43	0.133	0.211	0.234	1104
28 "	57	0.138	0.218	0.246	1160
27 May	86	0.147	0.231	0.268	1264
29 June	118	0.153	0.238	0.281	1325
28 July	147	0.160	0.246	0.296	1396
8 Oct.	219	0.170	0.257	0.317	1495
26 Nov.	268	0.183	0.272	0.345	1627
28 Jan., '55	331	0.189	0.279	0.358	1689

Table 29. Average strain in CW 3.

Date	Age in Days	Berry Gage Reading Left	Berry Gage Reading Right	Sum Total Dial Change	Average Strain 10^{-6} in/in.
13 Mar.,'54	0	-	-	Made	
15 "	2	0.007	0.056	No Force	-
15 "	2	0.025	0.067	0.029	137(Partial)
18 "	5	0.032	0.083	0.052	245
18 "	5	0.083	0.112	0.132	623(Final)
20 "	7	0.104	0.123	0.164	774
27 "	14	0.098	0.137	0.172	811
3 April	21	0.112	0.149	0.198	934
10 "	28	0.112	0.149	0.198	934
23 "	41	0.124	0.160	0.221	1042
6 May	54	0.133	0.168	0.238	1123
29 "	77	0.143	0.177	0.257	1212
29 June	108	0.147	0.181	0.265	1250
28 July	137	0.152	0.185	0.275	1297
8 Oct.	209	0.164	0.196	0.297	1401
26 Nov.	258	0.179	0.209	0.325	1533
28 Jan.,'55	321	0.186	0.215	0.338	1594

Table 30. Average strain in CW 4.

Date	Age in Days	Berry Gage Reading Left	Right	Sum Total Dial Change	Average Strain 10^{-6} in/in.
9 Mar., '54	0	-	-	Made	
11 "	2	0.009	0.009	No Force	-
11 "	2	0.022	0.015	0.019	90(Partial)
12 "	3	0.022	0.055	(Change of holes)	-
15 "	6	0.034	0.027	0.043	203
15 "	6	0.052	0.054	0.088	415(Final)
17 "	8	0.065	0.098	0.145	684
24 "	15	0.070	0.104	0.156	736
31 "	23	0.077	0.125	0.184	870
7 April	30	0.082	0.132	0.196	925
21 "	44	0.091	0.147	0.220	1038
5 May	58	0.100	0.161	0.243	1146
27 "	80	0.103	0.139	0.224	1057
29 June	112	0.107	0.147	0.236	1113
28 July	141	0.113	0.174	0.269	1266
8 Oct.	213	0.124	0.187	0.293	1382
26 Nov.	262	0.136	0.202	0.320	1509
28 Jan., '55	325	0.141	0.205	0.328	1547

Table 31. Average strain in CW 5.

Date	Age in Days	Berry Gage Reading		Sum Total Dial Change	Average Strain 10^{-6} in/in.
		Left	Right		
10 Mar.,'54	0	-	-	Made	
12 "	2	0.066	0.058	No Force	-
12 "	2	0.084	0.070	0.030	142(Partial)
17 "	7	0.094	0.075	0.045	212
17 "	7	0.155	0.101	0.132	623(Final)
20 "	10	0.167	0.109	0.152	717
27 "	17	0.168	0.134	0.178	840
3 April	24	0.083	0.121	0.080	377
10 "	31	0.093	0.117	0.086	406
23 "	44	0.101	0.123	0.100	472
6 May	57	0.110	0.135	0.121	571
29 "	80	0.118	0.138	0.132	623
29 June	111	0.121	0.140	0.137	646
28 July	140	0.128	0.146	0.150	708
8 Oct.	212	0.140	0.157	0.173	816
26 Nov.	261	0.153	0.170	0.199	939
28 Jan.,'55	324	0.152	0.169	0.197	929

Table 32. Average strain in CW 6.

Date	Age in Days	Berry Gage Reading		Sum Total Dial Change	Average Strain 10^{-6} in/in.
		Left	Right		
4 Mar.,'54	0	-	-	Made	
6 "	2	0.049	0.021	No Force	-
6 "	2	0.067	0.044	0.046	217(Partial)
18 "	14	0.098	0.051	0.060	283
18 "	14	0.051	0.100	0.158	745(Final)
20 "	16	0.064	0.081	0.120	566
26 "	22	0.067	0.114	0.186	877
2 April	29		0.125	0.208	981
9 "	36		0.132	0.222	1047
15 "	42		0.132	0.222	1047
1 May	58		0.145	0.248	1170
22 "	79		0.150	0.258	1217
29 June	117		0.157	0.272	1283
28 July	146		0.163	0.284	1340
8 Oct.	218		0.174	0.306	1443
26 Nov.	267		0.180	0.318	1500
28 Jan.,'55	330		0.189	0.336	1585

Table 33. Average strain in CW 7.

Date	Age in Days	Berry Gage Reading Left	Berry Gage Reading Right	Sum Total Dial Change	Average Strain 10^{-6} in/in.
11 Mar.,'54	0	-	—	Made	
13 "	2	0.052	0.001	No Force	-
13 "	2	0.066	0.006	0.019	90(Partial)
20 "	9	0.075	0.021	0.043	203
1 April	21	0.079	0.026	0.052	245
1 "	21	0.114	0.076	0.137	646(Final)
3 "	23	0.120	0.089	0.156	736
10 "	30	0.123	0.097	0.167	788
21 "	41	0.131	0.103	0.181	838
28 "	48	0.135	0.108	0.190	896
11 May	61	0.145	0.122	0.214	1009
27 "	77	0.145	0.118	0.210	991
29 June	110	0.151	0.132	0.230	1085
28 July	139	0.158	0.140	0.245	1156
8 Oct.	211	0.170	0.155	0.272	1283
26 Nov.	260	0.184	0.170	0.301	1420
28 Jan.,'55	323	0.186	0.171	0.304	1434

Table 34. Average strain in CW 8.

Date	Age in Days	Berry Gage Reading		Sum Total Dial Change	Average Strain 10^{-6} in/in.
		Left	Right		
3 Mar.,'54	0	-	-	Made	
5 "	2	0.000	0.032	No Force	—
5 "	2	0.012	0.047	0.027	127(Partial)
12 "	9	0.026	0.046	0.040	189
19 "	16	0.040	0.057	0.065	307
31 "	28	0.043	0.155	0.166	783
31 "	28	0.110	0.192	0.270	1274(Final)
2 April	30	0.115	0.210	0.293	1382
9 "	37	0.120	0.217	0.305	1439
15 "	43	0.123	0.220	0.311	1467
23 "	51	0.130	0.226	0.324	1528
5 May	63	0.141	0.241	0.350	1651
29 "	88	0.146	0.249	0.363	1712
29 June	118	0.150	0.256	0.374	1764
28 July	147	0.158	0.269	0.395	1863
8 Oct.	219	0.170	0.289	0.427	2014
28 Nov.	268	0.184	0.313	0.465	2193
28 Jan.,'55	331	0.188	0.320	0.467	2203

Table 35. Average strain in CW 9.

Date	Age in Days	Berry Gage Reading		Sum Total Dial Change	Average Strain 10^{-6} in/in.
		Left	Right		
6 Mar.,'54	0	-	-	Made	
13 "	7	0.020	0.026	No Force	-
13 "	7	0.090	0.112	0.156	736(Final)
15 "	9	0.098	0.128	0.180	849
23 "	17	0.110	0.154	0.218	1023
31 "	25	0.124	0.141	0.219	1033
6 April	31	0.118	0.168	0.240	1132
21 "	46	0.126	0.176	0.256	1208
5 May	60	0.135	0.203	0.294	1387
27 "	82	0.137	0.194	0.285	1344
29 June	115	0.143	0.214	0.311	1467
28 July	144	0.150	0.221	0.325	1533
8 Oct.	216	0.162	0.235	0.351	1656
26 Nov.	265	0.173	0.142	0.369	1741
28 Jan.,'55	328	0.176	0.145	0.375	1769

Table 36. Average strain in CW 10.

Date	Age in Days	Berry Gage Reading Left	Berry Gage Reading Right	Sum Total Dial Change	Average Strain 10^{-6} in/in.
17 Mar.,'54	0	-	-	Made	
31 "	14	-0.130	-0.134	No Force	-
31 "	14	-0.077	-0.080	0.107	505(Final)
2 April	16	0.026	0.030	0.320	1509
9 "	23	0.045	0.043	0.352	1660
15 "	29	0.047	0.045	0.356	1679
23 "	37	0.052	0.052	0.368	1736
6 May	50	0.062	0.062	0.388	1830
29 "	73	0.066	0.068	0.398	1877
29 June	104	0.069	0.069	0.402	1896
28 July	133	0.075	0.075	0.414	1953
8 Oct.	205	0.085	0.085	0.434	2047
26 Nov.	254	0.096	0.098	0.458	2160
28 Jan.,'55	317	0.095	0.097	0.456	2151

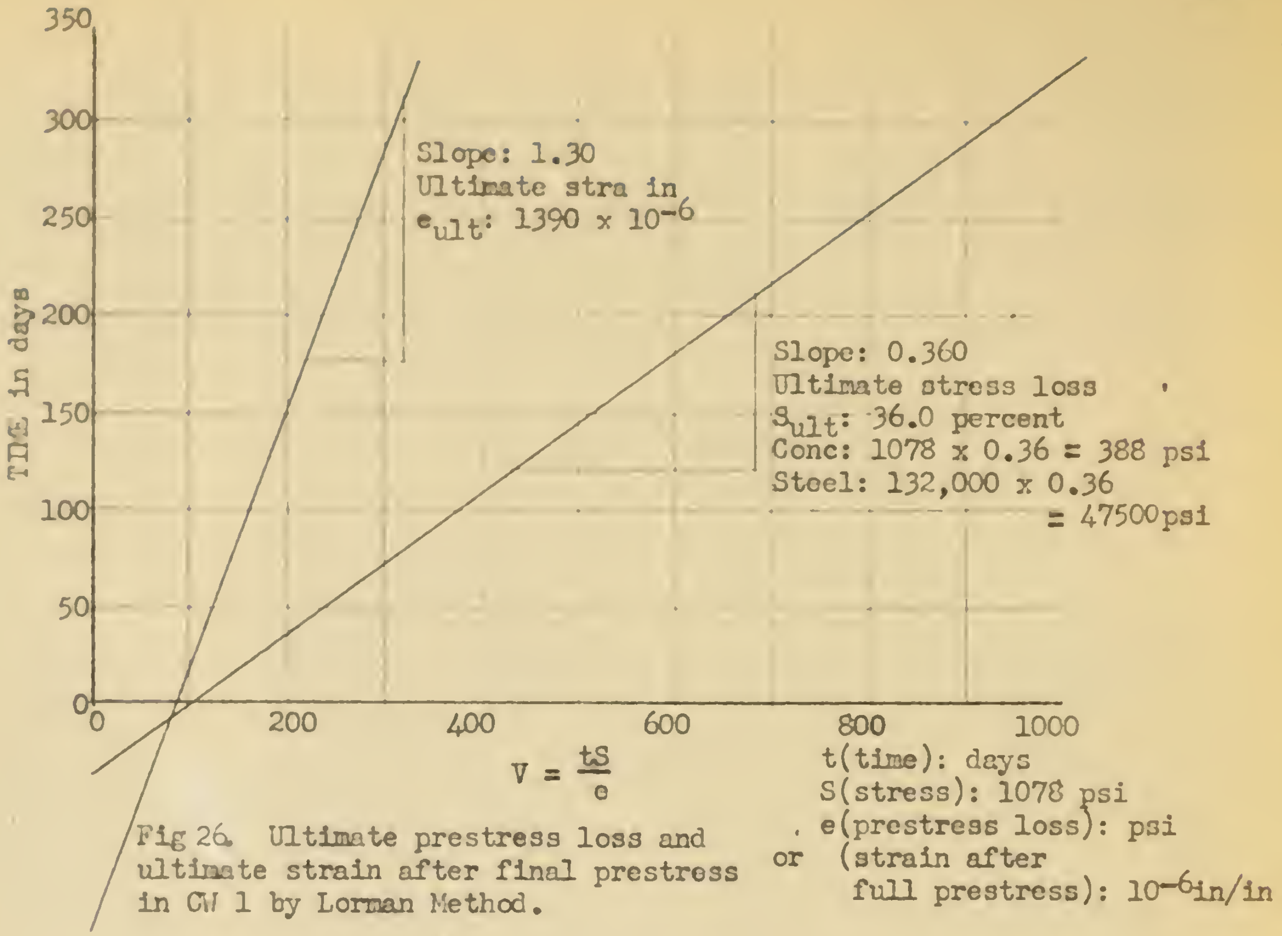


Fig 26. Ultimate prestress loss and ultimate strain after final prestress in CW 1 by Lorman Method.

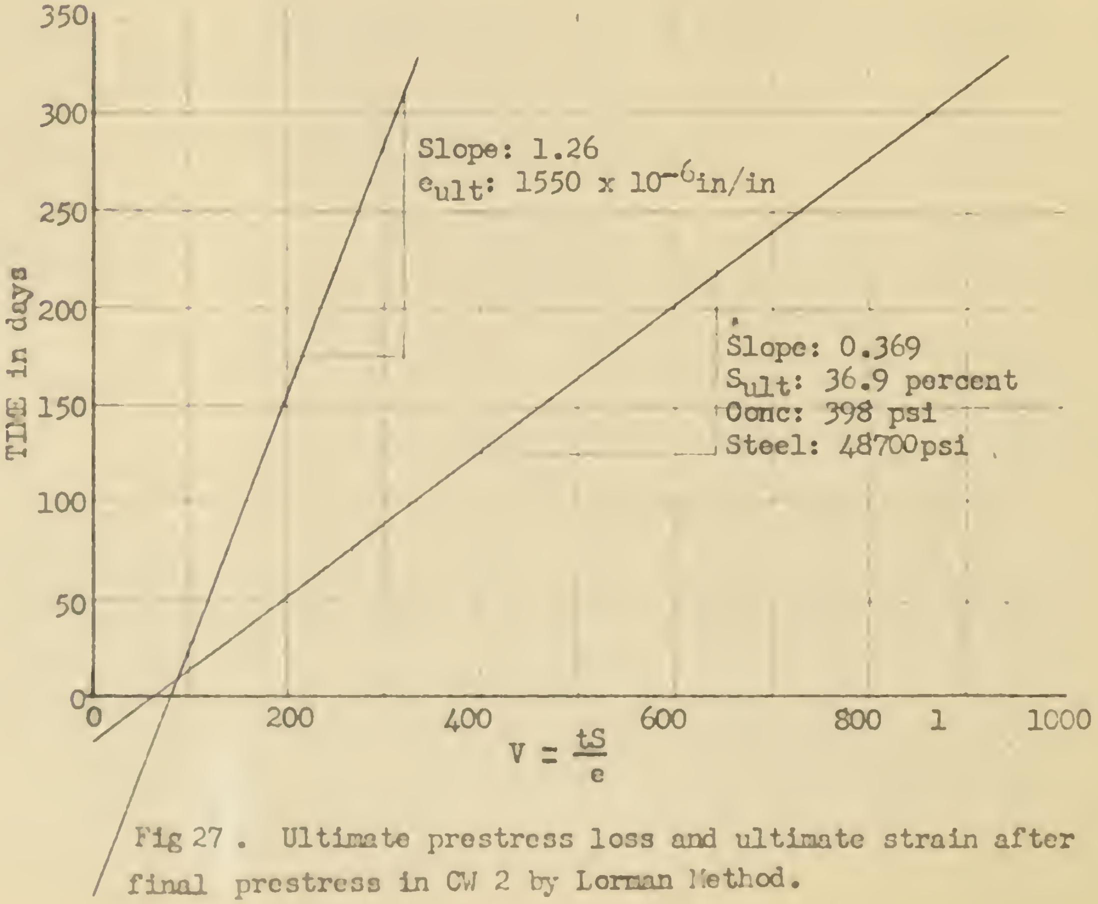


Fig 27. Ultimate prestress loss and ultimate strain after final prestress in CW 2 by Lorman Method.

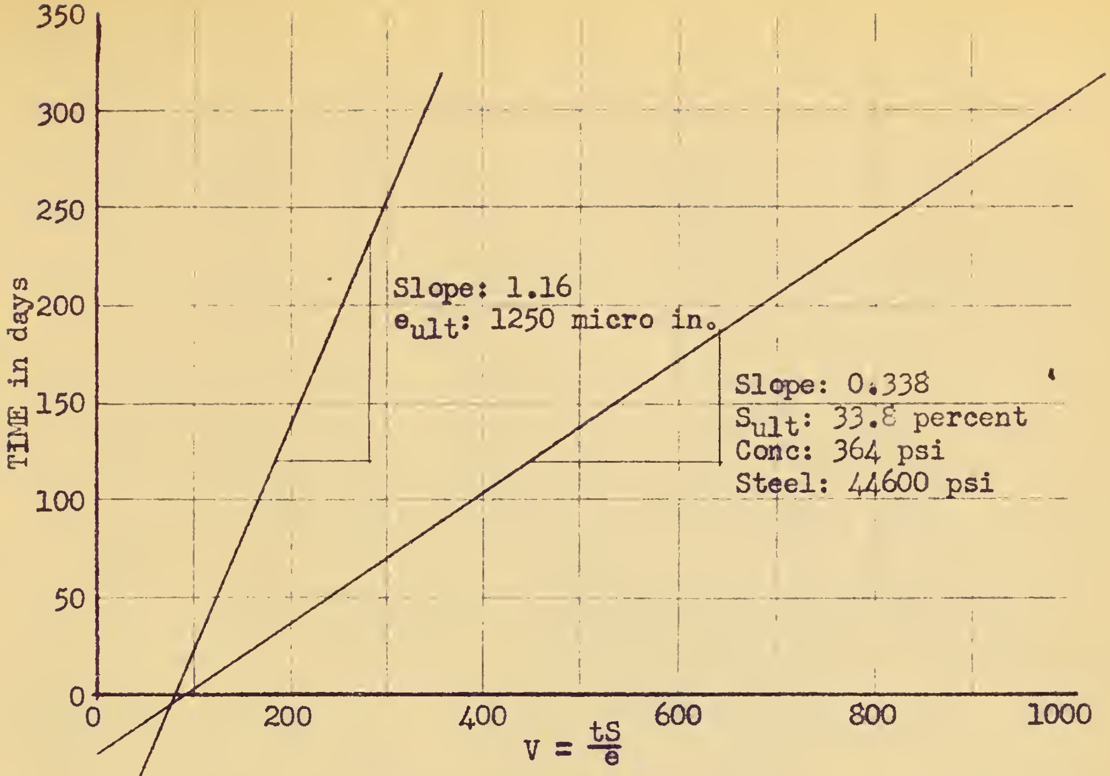


Fig. 28. Ultimate prestress loss and ultimate strain after final prestress in CW 3 by Lorman Method.

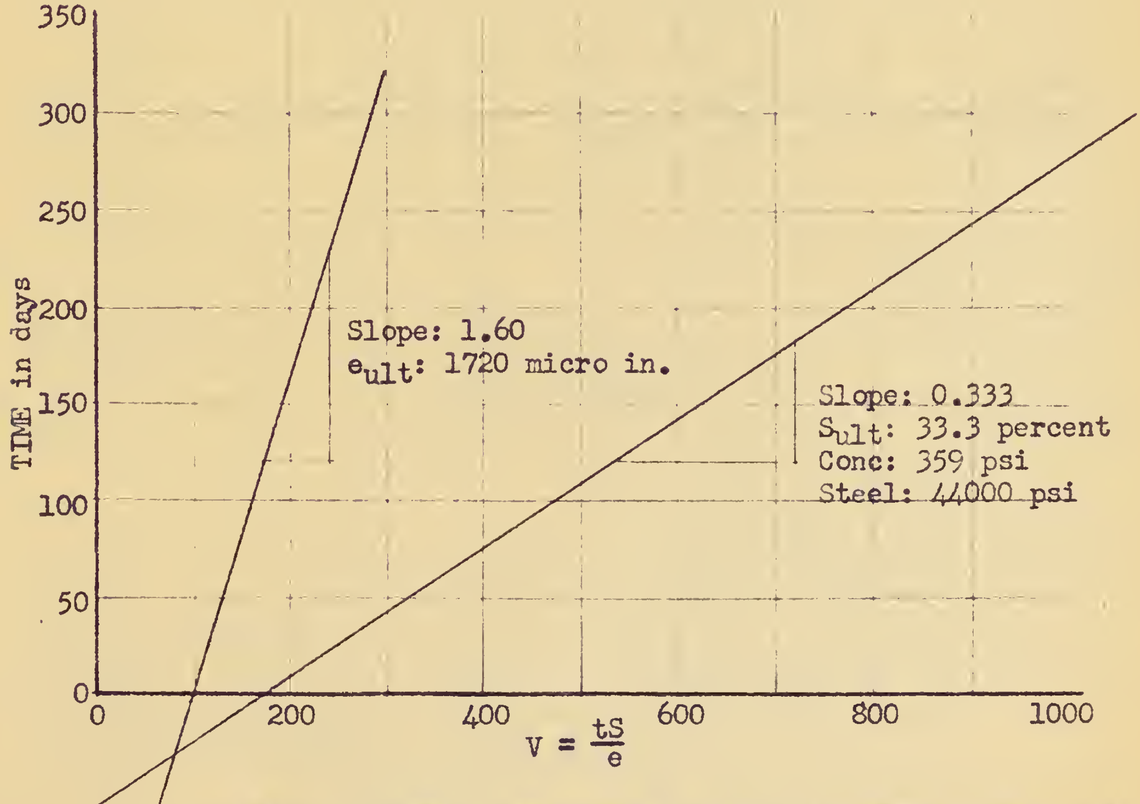


Fig. 29. Ultimate prestress loss and ultimate strain after final prestress in CW 4 by Lorman Method.

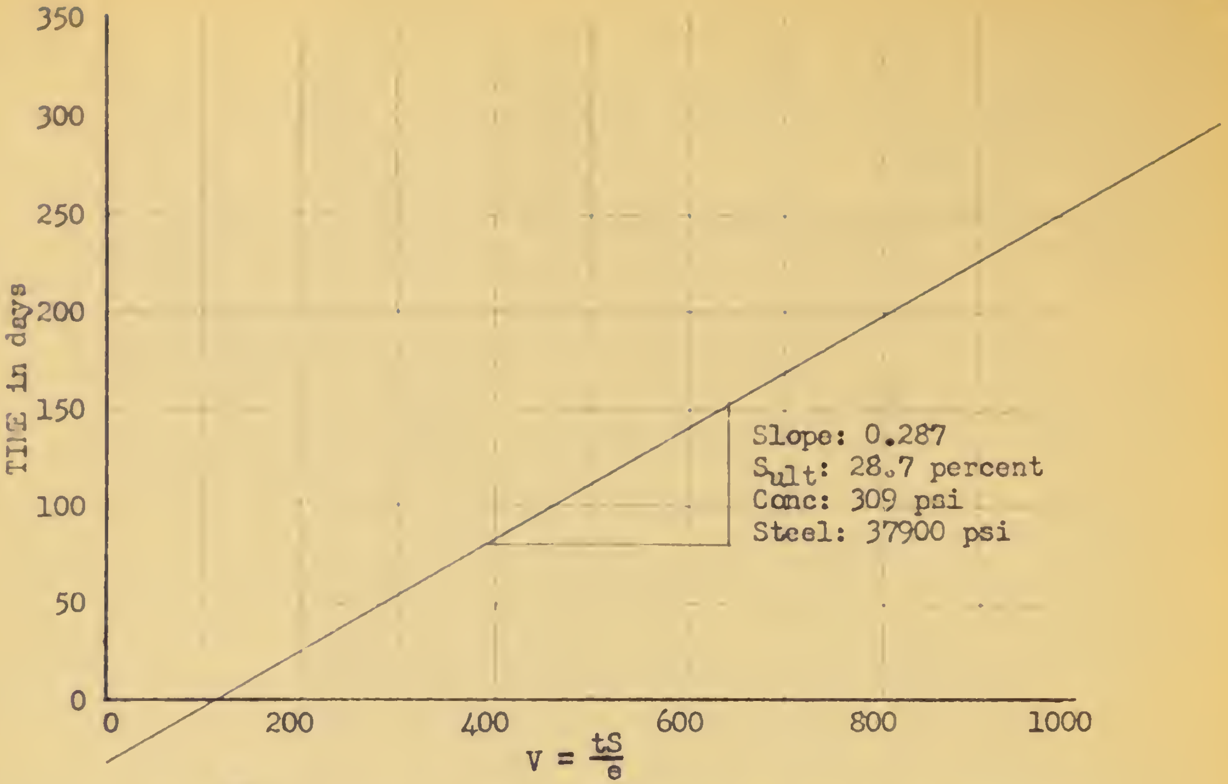


Fig. 30 . Ultimate prestress loss after final prestress in CW 5 by Lorman Method.

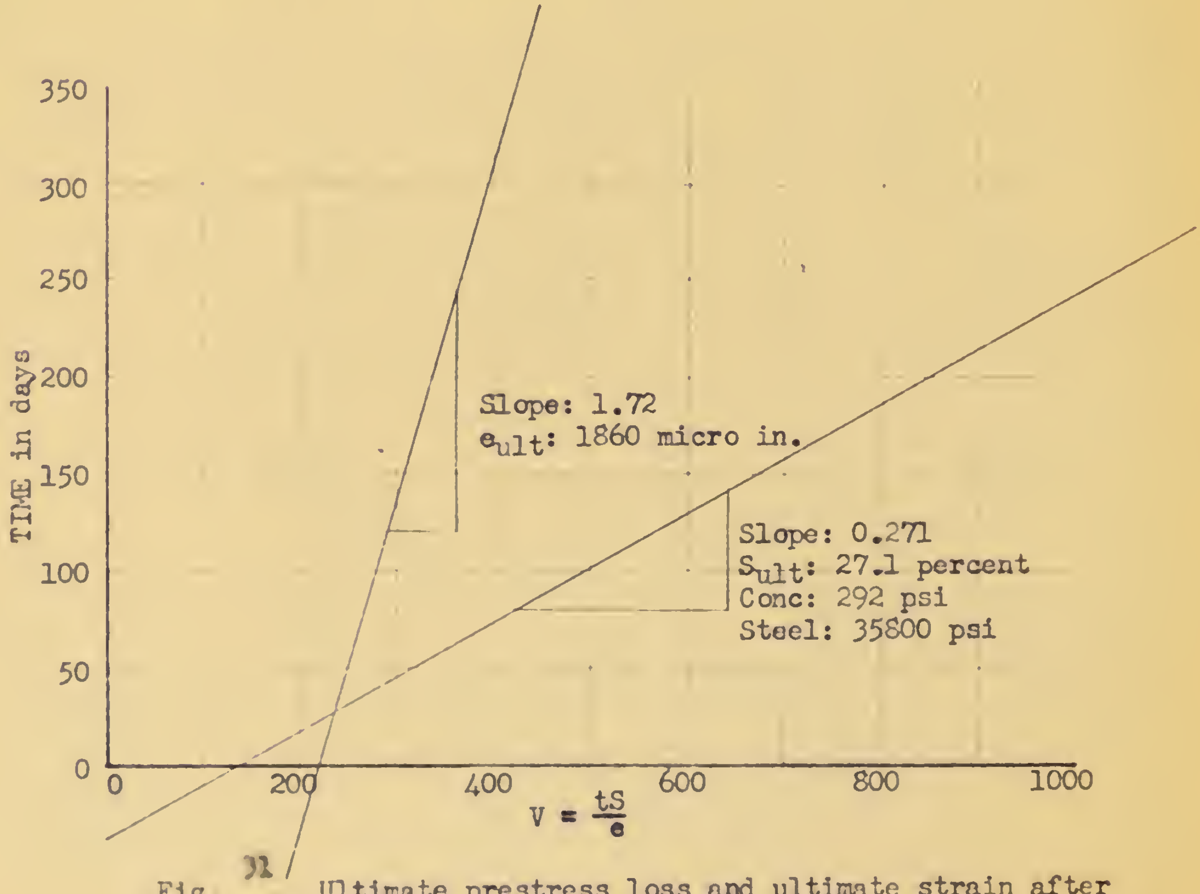


Fig. 31 . Ultimate prestress loss and ultimate strain after final prestress in CW 6 by Lorman Method.

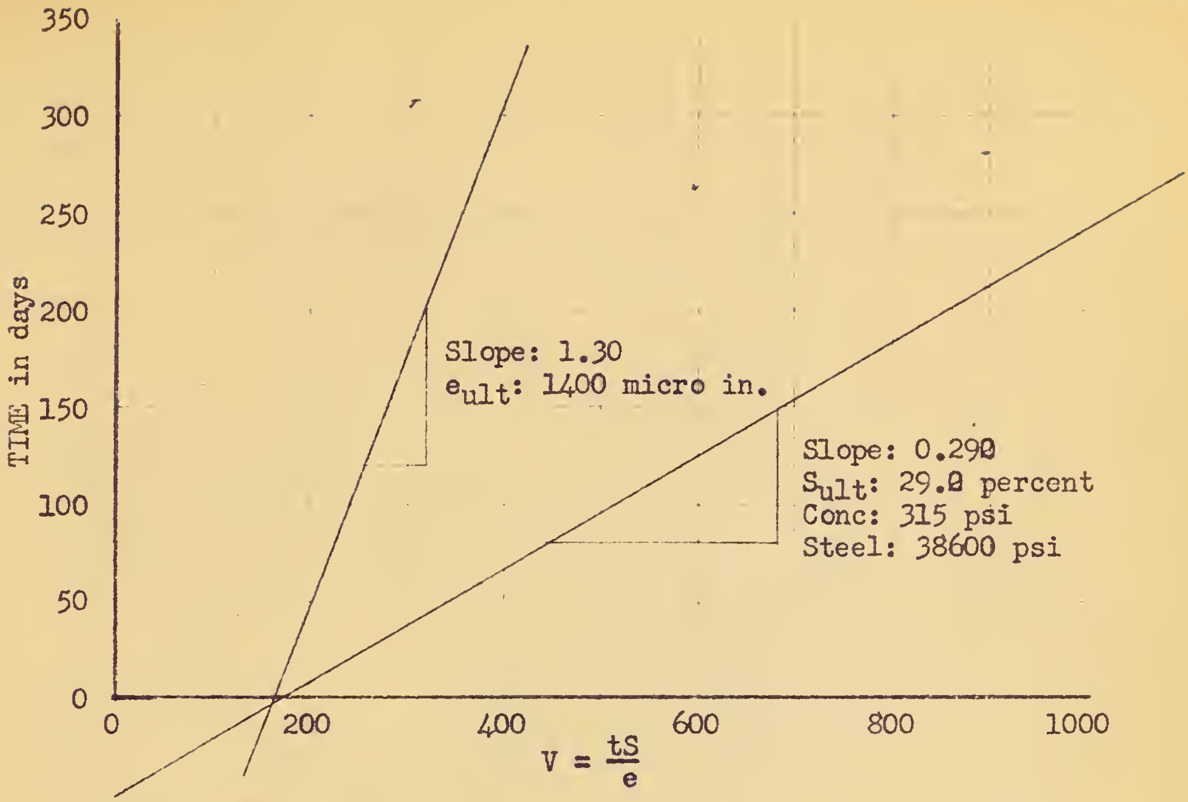


Fig. 32. Ultimate prestress loss and ultimate strain after final prestress in CW 7 by Lorman Method.

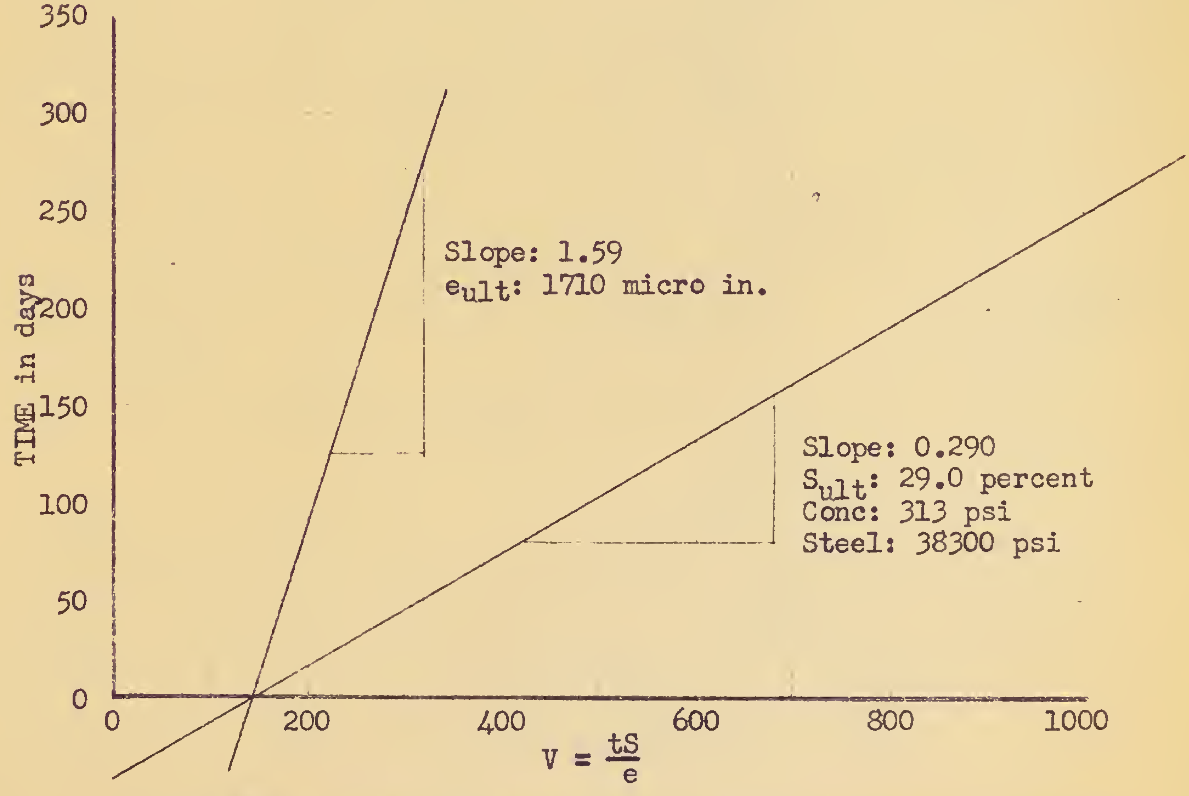


Fig. 33. Ultimate prestress loss and ultimate strain after final prestress in CW 8 by Lorman Method.

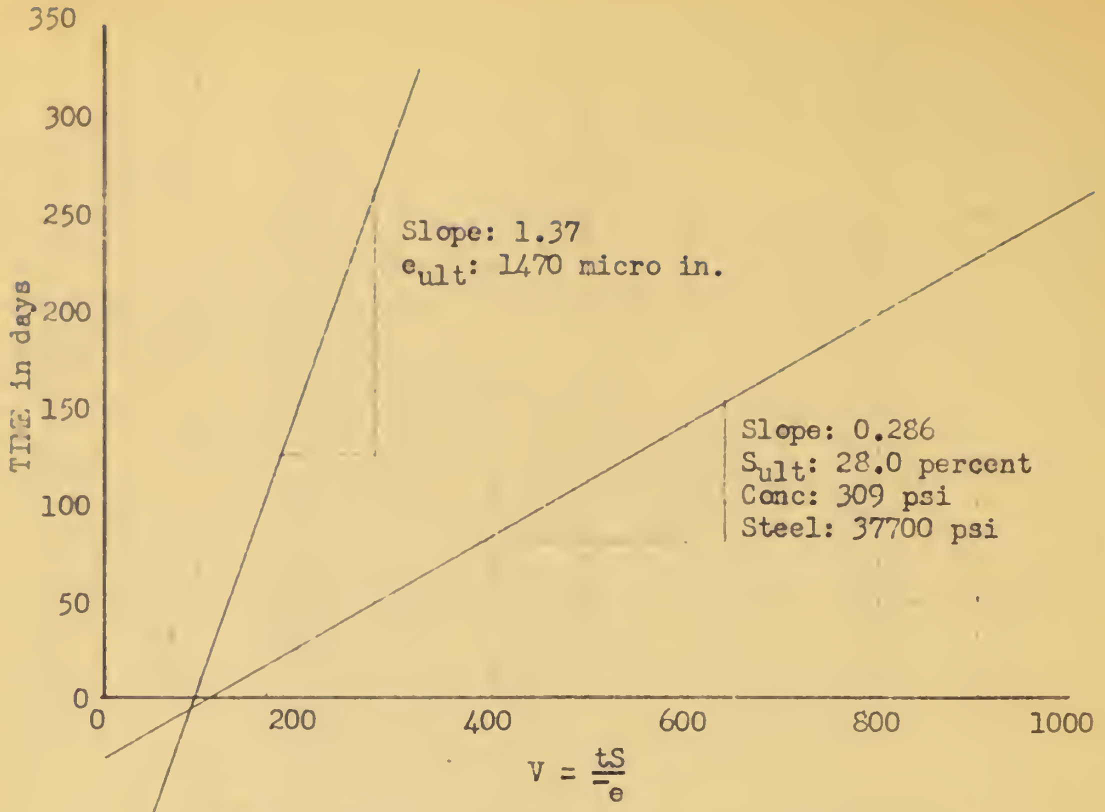


Fig. 34 . Ultimate prestress loss and ultimate strain after final prestress in CW 9 by Lorman Method.

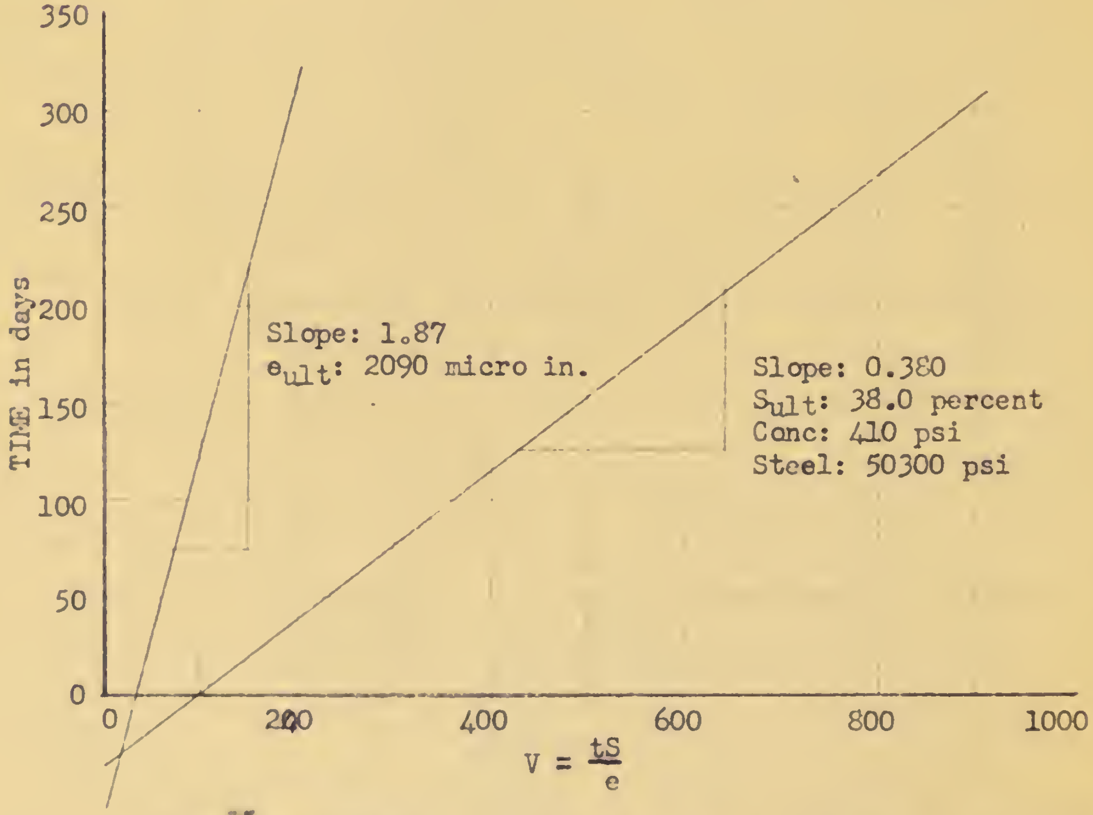


Fig. 35 . Ultimate prestress loss and ultimate strain after final prestress in CW 10 by Lorman Method.

Table 37. Shrinkage, creep and gross strain of CW 2 control beam.

Date	Age in Days	E			F			Creep Strain (Gross-Shrinkage)
		Gage Dial		Gross Strain 10^{-6} in/in.	Gage Dial		Shrinkage Strain 10^{-6} in/in.	
		1	2		1	2		
22 Oct.,'53	0	--	--	--	--	--	Made	--
24 "	2	0.550	0.879	--	400	697	No Force	--
24 "	2	0.610	0.937	134	(Instantaneous elastic strain)			Partial
26 "	4	0.650	0.968	80	429	710	47	37
26 "	4	0.829	1.139	396	(Instantaneous elastic strain)			Final
2 Nov.	11	0.959	1.252	355	449	790	160	195
9 "	18	1.028	1.330	522	519	818	271	251
23 "	32	1.110	1.410	705	560	891	400	305
14 Dec.	53	1.190	1.490	886	630	960	558	328
11 Jan.,'54	81	1.260	1.551	1034	670	1002	650	384
8 Feb.	109	1.271	1.580	1079	671	1010	660	420
8 Mar.	137	1.320	1.620	1180	702	1031	719	461
5 Apr.	165	1.348	1.650	1246	721	1050	762	484
3 May	193	1.349	1.650	1247	700	1029	715	532
31 "	221	1.325	1.630	1198	680	1010	671	527
28 June	249	1.330	1.620	1192	691	991	661	541
13 July	264	1.350	1.630	1226	700	1011	694	542
13 "	Placed in water tank for further testing.							

Table 38. Shrinkage, creep and gross strain in CW 5 control beam.

Date	Age in Days	E			F			Creep Strain (Gross-Shrinkage)
		Gage Dial 1	Gage Dial 2	Gross Strain 10^{-6} in/in.	Gage Dial 1	Gage Dial 2	Shrinkage Strain 10^{-6} in/in.	
22 Oct., '53	0	—	—	—	—	—	Made	—
24 "	2	0.538	0.588	—	578	500	No Force	—
24 "	2	0.588	0.648	110	(Instantaneous elastic strain)			Partial
26 "	4	0.629	0.699	104	610	509	46	58
29 "	7	0.659	0.730	173	620	549	103	70
29 "	7	0.808	0.909	372	(Instantaneous elastic strain)			Final
5 Nov.	14	0.920	1.029	435	650	600	195	240
12 "	21	0.959	1.071	527	698	629	282	245
26 "	35	1.030	1.150	596	758	671	397	299
17 Dec.	56	1.103	1.240	882	821	731	539	346
14 Jan., '54	84	1.148	1.292	991	850	760	602	389
11 Feb.	112	1.170	1.329	1058	870	780	647	411
11 Mar.	140	1.201	1.351	1119	890	801	694	425
8 April	168	1.212	1.370	1153	890	801	694	459
6 May	196	1.235	1.380	1190	900	810	715	475
3 June	224	1.230	1.377	1181	890	790	681	500
1 July	252	1.220	1.370	1161	880	780	659	502
13 "	265	1.220	1.360	1150	880	780	659	491
13 "	Placed in water tank for further testing.							

Table 39. Shrinkage, creep and gross strain in CW 7 control beam.

Date	Age in Days	E			F			G			Creep Strain (Gross-Shrink.)
		Gage 1	Dial 2	Gross Strain 10⁻⁶ in/in.	Gage 1	Dial 2	Shrinkage Strain 10⁻⁶ in/in.	Gage 1	Dial 2	Shrinkage Strain 10⁻⁶ in/in.	
13 Oct., '53	0									Made	
15 "	2	0.400	0.309	-	0.439	0.690	-	0.219	0.421	No Force	-
15 "	2	0.480	0.360	148	(Instantaneous elastic strain)					Partial	
20 "	7	0.549	0.412	137	0.490	0.712	82	0.270	0.441	80	56
27 "	14	0.609	0.470	271	0.540	0.740	171	0.330	0.461	171	100
3 Nov.	21	0.640	0.500.	340	0.539	0.801	239	0.320	0.529	237	102
3 "	21	0.800	0.600	294	(Instantaneous elastic strain)					Final	
10 "	28	0.860	0.652	467	0.550	0.830	284	0.349	0.548	292	179
24 "	42	0.940	0.711	624	0.608	0.860	374	0.398	0.580	383	241
15 Dec.	63	1.028	0.780	802	0.660	0.922	513	0.450	0.642	512	290
12 Jan., '54	91	1.091	0.840	941	0.720	0.970	635	0.501	0.700	635	306
9 Feb.	111	1.120	0.852	987	0.721	0.980	648	0.510	0.709	656	335
9 Mar.	147	1.170	0.909	1109	0.757	1.021	745	0.548	0.748	744	369
6 Apr.	175	1.170	0.911	1110	0.750	1.021	727	0.540	0.749	735	380
4 May	203	1.230	0.960	1234	0.782	1.050	796	0.580	0.780	814	429
28 June	231	1.180	0.930	1144	0.730	1.002	683	0.520	0.730	691	457
13 July	246	1.200	0.930	1167	0.760	1.020	737	0.540	0.730	714	441
13 "	Placed in water tank to soak for further testing.										

Table 40. Shrinkage, creep and gross strain of CW 9 control beam.

Date	Age in Days	E			F			G			Creep Strain (Gross-Shrink.)
		Gage Dial 1	Gage Dial 2	Gross Strain 10^{-6}in/in.	Gage Dial 1	Gage Dial 2	Shrinkage Strain 10^{-6}in/in.	Gage Dial 1	Gage Dial 2	Shrinkage Strain 10^{-6}in/in.	
13 Oct.,'53	0			-			-			Made	
15 "	2	0.419	0.489	-	0.490	0.210	-	0.412	0.470	No Force	-
20 "	7	0.461	0.520	-	0.529	0.228	-	0.459	0.502	No Force	-
20 "	7	0.630	0.763	466	(Instantaneous elastic strain)					Final	-
27 "	14	0.739	0.929	311	0.580	0.240	71	0.520	0.519	88	231
10 Nov.	28	0.818	1.030	515	0.609	0.339	216	0.530	0.620	214	300
1 Dec.	49	0.909	1.129	730	0.679	0.396	360	0.609	0.670	360	370
29 "	77	0.972	1.220	905	0.731	0.441	470	0.661	0.728	485	428
26 Jan.,'54	105	1.020	1.260	1005	0.756	0.470	531	0.691	0.755	549	465
23 Feb.	133	1.051	1.301	1086	0.777	0.488	575	0.709	0.768	585	506
23 Mar.	161	1.079	1.330	1151	0.792	0.511	619	0.731	0.791	635	524
20 Apr.	189	1.090	1.360	1197	0.800	0.520	637	0.740	0.800	656	550
18 May	217	1.080	1.350	1175	0.786	0.507	607	0.721	0.780	611	566
15 June	245	1.057	1.325	1120	0.756	0.469	530	0.686	0.750	438	636
13 July	273	1.080	1.360	1186	0.770	0.490	569	0.711	0.770	589	607
13 "	Placed in water tank for further testing.										

THE EFFECTS OF PARTIAL PRESTRESSING ON NEWLY CAST HAYDITE BEAMS

by

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AN ABSTRACT OF
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ABSTRACT

For this project two sets of ten large square prisms with a six-inch square cross section, 120 inch length, and a hole down the center were made of lightweight aggregate concrete using Carter-Waters B-X Haydite and Incor high early-strength portland cement. All were post-tensioned by the Prestressed Incorporated six-wire system, the wires being threaded through the 1 3/4-inch hole, to a nominal prestress of 433 psi in the first set with a 53,200 psi stress in the steel, and to 1078 psi in the second set with a 132,000 psi stress in the steel. Eight specimens in both sets each had a partial prestress applied at two days of age and maintained for 1, 2, 3, 4, 5, 12, 19 and 26 days before final prestressing. Two specimens had no partial prestress applied, but were fully prestressed at 7 and 14 days.

The purpose of this project was to experimentally determine what effect this partial prestress had towards minimizing the prestress loss resulting from creep in the concrete and the steel. By measuring the stress remaining in the system at various ages, plots of the stress histories were drawn from whence the action of the partial prestress in reducing the prestress loss was observed. Examination of a summary of data indicated that an increase in the duration of partial prestressing reduced the amount of prestress loss. For a duration of partial load of not less than six days, the prestress loss was limited to 1078-760= 318 psi.

To better understand what part creep and shrinkage played in the total strain, small 3 by 4 by 16-inch control beams were made with concrete used for four of the large specimens of the first set and the gross (creep plus shrinkage) strain under a constant load of 1000 psi and shrinkage with no load were measured. The creep was found to be 2/5 of the gross strain, and could reasonably be assumed to increase proportionately with increase of load intensity. Shrinkage strain, 3/5 of gross, would be expected to occur regardless of what intensity of load were applied. It should be pointed out that this shrinkage loss was for the small control beams.

The modulus of rupture and compressive strength of each mix for each large specimen was measured at the age of partial prestressing and final prestressing, and at 28 days by testing additional control beams from each batch in simple flexure and as a modified cube. All specimens possessed reasonable strengths.

The conclusion drawn from the observation of stress histories was that, for design purposes using Haydite aggregate, a design stress of 90,000 psi in the steel is indicated if an initial prestress of 1000 psi in the concrete due to a steel stress of 132,000 psi applied after a partial prestress has been acting on the concrete for not less than six days. It is also pointed out, however, that this recommendation is highly conservative.