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
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 inbedding 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.
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, dried 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>
<thead>
<tr>
<th>Sieve Size</th>
<th>Cumulative Percent Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4</td>
<td>21.4</td>
</tr>
<tr>
<td>8</td>
<td>48.3</td>
</tr>
<tr>
<td>16</td>
<td>71.2</td>
</tr>
<tr>
<td>30</td>
<td>88.4</td>
</tr>
<tr>
<td>-30</td>
<td>100.0</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Pounds Retained</th>
<th>Pounds per Bag</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4</td>
<td>653</td>
<td>32.7</td>
</tr>
<tr>
<td>8</td>
<td>536</td>
<td>31.3</td>
</tr>
<tr>
<td>16</td>
<td>363</td>
<td>18.1</td>
</tr>
<tr>
<td>30</td>
<td>542</td>
<td>27.1</td>
</tr>
<tr>
<td>-30</td>
<td>98</td>
<td>4.9</td>
</tr>
</tbody>
</table>

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 lb per cu ft

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
  \( (1.1 \text{ yd} \times 27 \text{ cu ft per yd}) \times 60.1 \text{ lb per cu ft}) \)
- 6.75 sacks cement = 635 lb cement
  \( (6.75 \text{ sacks} \times 94 \text{ lb per sack}) \)
- 7.5 gal. water per sack cement = 422 lb water
  \( (7.5 \text{ gal.} \times 3.33 \text{ lb per gal.} \times 6.75 \text{ sacks}) \)

The quantities used for each mix were,
236.8 lb of aggregate

\[(236.8 \times 1785) \times 635 \text{ lb} = 83.85 \text{ lb cement}\]

\[(236.8 \times 1785) \times 422 \text{ lb} = 56.13 \text{ lb water (increased to 61.13 lb for greater workability)}\]

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 1073 psi in the second set was applied as shown in Table 3.

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

<table>
<thead>
<tr>
<th>Specimen Designation</th>
<th>Partial Prestress in days</th>
<th>Duration of Partial Prestress in days</th>
<th>Final Prestress in days</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW 1</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>CW 2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>CW 3</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>CW 4</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>CW 5</td>
<td>2</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>CW 6</td>
<td>2</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>CW 7</td>
<td>2</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>CW 8</td>
<td>2</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td>CW 9</td>
<td>None</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>CW 10</td>
<td>None</td>
<td>-</td>
<td>14</td>
</tr>
</tbody>
</table>
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 6 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 23 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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EXPLANATION OF PLATE III

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

Jack mounted on end of large specimen and showing working arrangement of prestressing hardware.
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 re-
leased, 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 speci-
mens, 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 fre-
sequently 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:

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

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 \( \frac{240}{433} = 55 \) percent, whereas, CW 4 had 210 psi remaining or a loss of \( \frac{223}{433} = 52 \) 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 prestress- ing 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 30-day readings of CW 1 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 30 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 Loman prediction of ultimate prestress loss for second set.

* Concrete stress in psi.
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
43,800 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 err-
ratic 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 303 psi in the steel. CW 4 had lost 223 psi = 21.2 percent
which is a 23,000 psi stress loss in the steel.

At 100 days, CW 6 had lost 218 psi, and CW 7, 193 psi; both read-
ings smaller by an average of 7.5 percent than the corresponding 30-
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 pre-
stress 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 in-
dication 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 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 \( V = \frac{kS}{e} \) 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, 1073 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 396 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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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 $1860 \times 10^{-6}$ in/in., an ultimate stress loss of $28 \times 1860 = 52,100$ psi which greatly exceeded the 35,300 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.

<table>
<thead>
<tr>
<th>Beam No.</th>
<th>Ultimate Strain: (10^{-6}) in./in.</th>
<th>Steel Stress Loss: Strain (E): (% \times 132,000) psi</th>
<th>Prestress Loss: percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW 1</td>
<td>1390</td>
<td>38,900</td>
<td>47,500</td>
</tr>
<tr>
<td>CW 2</td>
<td>1350</td>
<td>37,800</td>
<td>48,700</td>
</tr>
<tr>
<td>CW 3</td>
<td>1250</td>
<td>35,000</td>
<td>44,600</td>
</tr>
<tr>
<td>CW 4</td>
<td>1720</td>
<td>48,200</td>
<td>44,000</td>
</tr>
<tr>
<td>CW 5</td>
<td>Readings too erratic</td>
<td></td>
<td>37,900</td>
</tr>
<tr>
<td>CW 6</td>
<td>1850</td>
<td>52,000</td>
<td>35,300</td>
</tr>
<tr>
<td>CW 7</td>
<td>1400</td>
<td>39,200</td>
<td>38,600</td>
</tr>
<tr>
<td>CW 8</td>
<td>1710</td>
<td>47,900</td>
<td>38,300</td>
</tr>
<tr>
<td>CW 9</td>
<td>1470</td>
<td>41,200</td>
<td>37,700</td>
</tr>
</tbody>
</table>

*\(E\) of the steel equals \(28 \times 10^6\) 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 $320/1073 \times 132,000 = 39,200$ 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 Haydlite 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 uniform-
ly 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.
Koenitzer, L. H. "Proposed Methods of Making Compression Tests on Portions of Concrete Beams from Flexure Tests."

Lorman, William R. "The Theory of Concrete Creep."

APPENDIX
APPENDIX

Equipment


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


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

$$S = Ee = \frac{\Delta L}{L} = 26 \times 10^6 \times \frac{1/16}{14 \times 12} = 14,000 \text{ psi}$$

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

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

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 $(42 + 1078) \times 100 = 4.5$ 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.

<table>
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<tr>
<th>Specimen</th>
<th>Date Made</th>
<th>Partial Prestress:</th>
<th>Final Prestress:</th>
<th>28-Day</th>
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<td>21 664 4825</td>
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<td>2 677 2955</td>
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Table 6. Strength data from control beams, second set.

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</table>
Concrete Stress vs Age

CW 1

Partial Prestress
Applied One Day

Fig. 6. CW 1 Stress Loss.
Concrete Stress vs. Age

CW 2

Partial prestress
applied two days.

Fig. 7. CW 2 stress loss.
Concrete Stress vs Age

CW 4

Partial Prestress
Applied Four Days.

Fig. 9. CW 4 Stress Loss.
**Concrete Stress vs. Age**

**CW 5**

Partial stress, applied five days.

![Graph showing stress vs. age for concrete](image)

---

Fig 10. CW 5 stress loss.
CONCRETE STRESS vs AGE

CW 6

PARTIAL PRESTRESS
APPLIED 12 DAYS.

Fig. 11. CW 6 stress loss. AGE in DAYS
CONCRETE STRESS vs AGE

CW 8

Partial Prestress
Applied 26 Days
40.2% Prestress
Applied 64 Days.

Fig. 13. CW 8 stress loss.
CONCRETE STRESS vs AGE

CW 9

40% PRESTRESS
APPLIED 94 DAYS

Fig 14. CW 9 stress loss.
Concrete Stress vs Age
CW 10
40.2% Prestress
Applied 63 Days.

Fig. 15. CW 10 Stress Loss.
Table 7. CW 1 stress, stress loss and age.

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Table 8. CW 2 stress, stress loss and age.
Table 9. CW 3 stress, stress loss and age.

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(Wire failed with full 1078 prestress attempt)
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## Table 14. CW 8 stress, stress loss and age.

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Fig 16. Concrete stress and concrete strain of CW 1.
Fig 17. Concrete stress and concrete strain of CII 2.
Fig. 18. Concrete stress and concrete strain of C1 3.
Fig 19. Concrete stress and concrete strain of CW A.
Fig. 21. Concrete stress and concrete strain of CW 6.
Fig 22. Concrete stress and concrete strain of C17.
Fig. 22. Concrete stress and concrete strain of CH 8.
Fig. 24: Concrete stress and concrete strain of Ch. 9.
Fig 25. Concrete stress and concrete strain of CW 10.
Table 17. CW 1 stress, stress loss and age.

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

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<th>Jack Gage Reading</th>
<th>Concrete Stress (psi)</th>
<th>Total Stress Loss (psi)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Mar., '54</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Made</td>
<td></td>
</tr>
<tr>
<td>13 &quot;</td>
<td>2</td>
<td>1450</td>
<td>260</td>
<td>Partial</td>
<td></td>
</tr>
<tr>
<td>20 &quot;</td>
<td>9</td>
<td>1150</td>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 April</td>
<td>21</td>
<td>950</td>
<td>140</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>1 &quot;</td>
<td>21</td>
<td>6030</td>
<td>1078</td>
<td>Full PS</td>
<td>70</td>
</tr>
<tr>
<td>3 &quot;</td>
<td>23</td>
<td>5650</td>
<td>1008</td>
<td></td>
<td>129</td>
</tr>
<tr>
<td>10 &quot;</td>
<td>30</td>
<td>5300</td>
<td>949</td>
<td></td>
<td>167</td>
</tr>
<tr>
<td>21 &quot;</td>
<td>41</td>
<td>5100</td>
<td>911</td>
<td></td>
<td>171</td>
</tr>
<tr>
<td>28 &quot;</td>
<td>48</td>
<td>5075</td>
<td>907</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 May</td>
<td>61</td>
<td>5100</td>
<td>911</td>
<td></td>
<td>167</td>
</tr>
<tr>
<td>27 &quot;</td>
<td>77</td>
<td>5050</td>
<td>903</td>
<td></td>
<td>175</td>
</tr>
<tr>
<td>29 June</td>
<td>110</td>
<td>4900</td>
<td>875</td>
<td></td>
<td>203</td>
</tr>
<tr>
<td>28 July</td>
<td>139</td>
<td>4775</td>
<td>851</td>
<td></td>
<td>227</td>
</tr>
<tr>
<td>8 Oct.</td>
<td>211</td>
<td>4700</td>
<td>838</td>
<td></td>
<td>240</td>
</tr>
<tr>
<td>26 Nov.</td>
<td>260</td>
<td>4625</td>
<td>823</td>
<td></td>
<td>255</td>
</tr>
<tr>
<td>28 Jan., '55</td>
<td>323</td>
<td>4600</td>
<td>820</td>
<td></td>
<td>258</td>
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</tbody>
</table>
Table 24. CW 8 stress, stress loss and age.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>Jack Gage</th>
<th>Concrete Stress</th>
<th>Total Stress Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Mar., '54</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Made</td>
</tr>
<tr>
<td>5 &quot;</td>
<td>2</td>
<td>1450</td>
<td>260</td>
<td>95</td>
</tr>
<tr>
<td>12 &quot;</td>
<td>9</td>
<td>1000</td>
<td>190</td>
<td>70</td>
</tr>
<tr>
<td>19 &quot;</td>
<td>16</td>
<td>950</td>
<td>181</td>
<td>79</td>
</tr>
<tr>
<td>31 &quot;</td>
<td>28</td>
<td>750</td>
<td>142</td>
<td>118</td>
</tr>
<tr>
<td>31 &quot;</td>
<td>28</td>
<td>6000</td>
<td>1070</td>
<td>Full PS</td>
</tr>
<tr>
<td>2 April</td>
<td>30</td>
<td>5450</td>
<td>975</td>
<td>95</td>
</tr>
<tr>
<td>9 &quot;</td>
<td>37</td>
<td>5150</td>
<td>922</td>
<td>148</td>
</tr>
<tr>
<td>15 &quot;</td>
<td>43</td>
<td>5150</td>
<td>922</td>
<td>148</td>
</tr>
<tr>
<td>23 &quot;</td>
<td>51</td>
<td>5050</td>
<td>903</td>
<td>167</td>
</tr>
<tr>
<td>5 May</td>
<td>63</td>
<td>4950</td>
<td>884</td>
<td>186</td>
</tr>
<tr>
<td>29 &quot;</td>
<td>88</td>
<td>4800</td>
<td>857</td>
<td>213</td>
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<tr>
<td>29 June</td>
<td>118</td>
<td>4800</td>
<td>857</td>
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<td>28 July</td>
<td>147</td>
<td>4700</td>
<td>838</td>
<td>232</td>
</tr>
<tr>
<td>8 Oct.</td>
<td>219</td>
<td>4600</td>
<td>820</td>
<td>250</td>
</tr>
<tr>
<td>26 Nov.</td>
<td>268</td>
<td>4500</td>
<td>802</td>
<td>268</td>
</tr>
<tr>
<td>28 Jan., '55</td>
<td>331</td>
<td>4475</td>
<td>799</td>
<td>271</td>
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</table>
### Table 25. CW 9 stress, stress loss and age.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>Jack Gage Reading</th>
<th>Concrete Stress psi</th>
<th>Total Stress Loss psi</th>
<th>Made</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Mar., '54</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Made</td>
</tr>
<tr>
<td>13 &quot;</td>
<td>7</td>
<td>6030</td>
<td>1078</td>
<td>Full PS</td>
<td>50</td>
</tr>
<tr>
<td>15 &quot;</td>
<td>9</td>
<td>5750</td>
<td>1028</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>23 &quot;</td>
<td>17</td>
<td>5750</td>
<td>1028</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>31 &quot;</td>
<td>25</td>
<td>5200</td>
<td>931</td>
<td>147</td>
<td></td>
</tr>
<tr>
<td>6 April</td>
<td>31</td>
<td>5200</td>
<td>931</td>
<td>147</td>
<td></td>
</tr>
<tr>
<td>21 &quot;</td>
<td>46</td>
<td>6025</td>
<td>897</td>
<td>181</td>
<td></td>
</tr>
<tr>
<td>5 May</td>
<td>50</td>
<td>4925</td>
<td>880</td>
<td>198</td>
<td></td>
</tr>
<tr>
<td>27 &quot;</td>
<td>82</td>
<td>4750</td>
<td>848</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>29 June</td>
<td>115</td>
<td>4725</td>
<td>840</td>
<td>238</td>
<td></td>
</tr>
<tr>
<td>28 July</td>
<td>144</td>
<td>4625</td>
<td>823</td>
<td>255</td>
<td></td>
</tr>
<tr>
<td>8 Oct.</td>
<td>216</td>
<td>4550</td>
<td>812</td>
<td>266</td>
<td></td>
</tr>
<tr>
<td>26 Nov.</td>
<td>265</td>
<td>4475</td>
<td>799</td>
<td>279</td>
<td></td>
</tr>
<tr>
<td>28 Jan., '55</td>
<td>328</td>
<td>4425</td>
<td>783</td>
<td>295</td>
<td></td>
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</table>
Table 26. CW 10 stress, stress loss and age.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>Jack Gage Reading</th>
<th>Concrete Stress psi</th>
<th>Total Stress Loss psi</th>
<th>Made</th>
<th>Full PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 Mar.,'54</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Made</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31 &quot;</td>
<td>14</td>
<td>6000</td>
<td>1070</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 April</td>
<td>16</td>
<td>5300</td>
<td>949</td>
<td>121</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 &quot;</td>
<td>23</td>
<td>5000</td>
<td>894</td>
<td>176</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 &quot;</td>
<td>29</td>
<td>4750</td>
<td>848</td>
<td>222</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23 &quot;</td>
<td>37</td>
<td>4800</td>
<td>857</td>
<td>213</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 May</td>
<td>50</td>
<td>4800</td>
<td>857</td>
<td>213</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 &quot;</td>
<td>73</td>
<td>4350</td>
<td>778</td>
<td>292</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 June</td>
<td>104</td>
<td>4400</td>
<td>781</td>
<td>289</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 July</td>
<td>133</td>
<td>4200</td>
<td>751</td>
<td>319</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Oct.</td>
<td>205</td>
<td>4100</td>
<td>730</td>
<td>340</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26 Nov.</td>
<td>254</td>
<td>4000</td>
<td>713</td>
<td>357</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 Jan.,'55</td>
<td>317</td>
<td>3950</td>
<td>710</td>
<td>360</td>
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<td></td>
</tr>
</tbody>
</table>
Table 27. Average strain in CW 1 (second set).

<table>
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<tr>
<th>Date</th>
<th>Age in Days</th>
<th>Berry Gage Reading</th>
<th>Sum Total</th>
<th>Average Strain: 10⁻⁶ in/in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 Feb., '54</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Made</td>
</tr>
<tr>
<td>1 Mar.</td>
<td>2</td>
<td>0.042</td>
<td>0.047</td>
<td>No Force</td>
</tr>
<tr>
<td>2 &quot;</td>
<td>3</td>
<td>0.072</td>
<td>0.057</td>
<td>0.040</td>
</tr>
<tr>
<td>2 &quot;</td>
<td>3</td>
<td>0.124</td>
<td>0.102</td>
<td>0.137</td>
</tr>
<tr>
<td>5 &quot;</td>
<td>6</td>
<td>0.142</td>
<td>0.112</td>
<td>0.165</td>
</tr>
<tr>
<td>12 &quot;</td>
<td>13</td>
<td>0.153</td>
<td>0.127</td>
<td>0.191</td>
</tr>
<tr>
<td>19 &quot;</td>
<td>20</td>
<td>0.165</td>
<td>0.140</td>
<td>0.216</td>
</tr>
<tr>
<td>26 &quot;</td>
<td>27</td>
<td>0.167</td>
<td>0.146</td>
<td>0.224</td>
</tr>
<tr>
<td>9 April</td>
<td>41</td>
<td>0.182</td>
<td>0.149</td>
<td>0.242</td>
</tr>
<tr>
<td>1 May</td>
<td>63</td>
<td>0.195</td>
<td>0.160</td>
<td>0.266</td>
</tr>
<tr>
<td>29 &quot;</td>
<td>91</td>
<td>0.160</td>
<td>0.167</td>
<td>0.239</td>
</tr>
<tr>
<td>29 June</td>
<td>122</td>
<td>0.206</td>
<td>0.160</td>
<td>0.227</td>
</tr>
<tr>
<td>28 July</td>
<td>151</td>
<td>0.213</td>
<td>0.178</td>
<td>0.302</td>
</tr>
<tr>
<td>8 Oct.</td>
<td>223</td>
<td>0.224</td>
<td>0.187</td>
<td>0.322</td>
</tr>
<tr>
<td>26 Nov.</td>
<td>272</td>
<td>0.240</td>
<td>0.201</td>
<td>0.352</td>
</tr>
<tr>
<td>28 Jan., '55</td>
<td>335</td>
<td>0.245</td>
<td>0.205</td>
<td>0.361</td>
</tr>
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</table>

Notes: Made - 188 (Partial), 646 (Final), 778, 901, 1019, 1057, 1141, 1255, 1127, 1307, 1425, 1519, 1660, 1703.
Table 28. Average strain in CW 2.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>Berry Cage Reading</th>
<th>Sum Total</th>
<th>Average Strain: $10^{-6}$ in/in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Mar.,'54</td>
<td>0</td>
<td>-</td>
<td>Made</td>
<td>-</td>
</tr>
<tr>
<td>4 &quot;</td>
<td>2</td>
<td>0.022</td>
<td>0.088</td>
<td>No Force</td>
</tr>
<tr>
<td>4 &quot;</td>
<td>2</td>
<td>0.033</td>
<td>0.105</td>
<td>0.028 (Partial)</td>
</tr>
<tr>
<td>6 &quot;</td>
<td>4</td>
<td>0.084</td>
<td>0.157</td>
<td>0.131 (Final)</td>
</tr>
<tr>
<td>9 &quot;</td>
<td>7</td>
<td>0.102</td>
<td>0.171</td>
<td>0.163</td>
</tr>
<tr>
<td>23 &quot;</td>
<td>21</td>
<td>0.120</td>
<td>0.199</td>
<td>0.209</td>
</tr>
<tr>
<td>31</td>
<td>29</td>
<td>0.120</td>
<td>0.204</td>
<td>0.214</td>
</tr>
<tr>
<td>14 April</td>
<td>43</td>
<td>0.133</td>
<td>0.211</td>
<td>0.234</td>
</tr>
<tr>
<td>28 &quot;</td>
<td>57</td>
<td>0.138</td>
<td>0.218</td>
<td>0.246</td>
</tr>
<tr>
<td>27 May</td>
<td>86</td>
<td>0.147</td>
<td>0.231</td>
<td>0.268</td>
</tr>
<tr>
<td>29 June</td>
<td>118</td>
<td>0.153</td>
<td>0.238</td>
<td>0.281</td>
</tr>
<tr>
<td>28 July</td>
<td>147</td>
<td>0.160</td>
<td>0.246</td>
<td>0.296</td>
</tr>
<tr>
<td>8 Oct.</td>
<td>219</td>
<td>0.170</td>
<td>0.257</td>
<td>0.317</td>
</tr>
<tr>
<td>26 Nov.</td>
<td>268</td>
<td>0.183</td>
<td>0.272</td>
<td>0.345</td>
</tr>
<tr>
<td>28 Jan.,'55</td>
<td>331</td>
<td>0.189</td>
<td>0.279</td>
<td>0.358</td>
</tr>
</tbody>
</table>
Table 29. Average strain in CW 3.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>Berry Gage Left</th>
<th>Berry Gage Right</th>
<th>Sum Total Dial Change</th>
<th>Average Strain: $10^{-6}$ in/in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 Mar., '54</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>Made: No Force</td>
<td>-</td>
</tr>
<tr>
<td>15 &quot;</td>
<td>2</td>
<td>0.007</td>
<td>0.056</td>
<td></td>
<td>137 (Partial)</td>
</tr>
<tr>
<td>18 &quot;</td>
<td>5</td>
<td>0.032</td>
<td>0.083</td>
<td>0.029</td>
<td>245</td>
</tr>
<tr>
<td>18 &quot;</td>
<td>5</td>
<td>0.083</td>
<td>0.112</td>
<td>0.132</td>
<td>623 (Final)</td>
</tr>
<tr>
<td>20 &quot;</td>
<td>7</td>
<td>0.104</td>
<td>0.123</td>
<td>0.164</td>
<td>774</td>
</tr>
<tr>
<td>27 &quot;</td>
<td>14</td>
<td>0.098</td>
<td>0.137</td>
<td>0.172</td>
<td>811</td>
</tr>
<tr>
<td>3 April</td>
<td>21</td>
<td>0.112</td>
<td>0.149</td>
<td>0.198</td>
<td>934</td>
</tr>
<tr>
<td>10 &quot;</td>
<td>28</td>
<td>0.112</td>
<td>0.149</td>
<td>0.198</td>
<td>934</td>
</tr>
<tr>
<td>23 &quot;</td>
<td>41</td>
<td>0.124</td>
<td>0.160</td>
<td>0.221</td>
<td>1042</td>
</tr>
<tr>
<td>6 May</td>
<td>54</td>
<td>0.133</td>
<td>0.168</td>
<td>0.238</td>
<td>1123</td>
</tr>
<tr>
<td>29 &quot;</td>
<td>77</td>
<td>0.143</td>
<td>0.177</td>
<td>0.257</td>
<td>1212</td>
</tr>
<tr>
<td>29 June</td>
<td>108</td>
<td>0.147</td>
<td>0.181</td>
<td>0.265</td>
<td>1250</td>
</tr>
<tr>
<td>28 July</td>
<td>137</td>
<td>0.152</td>
<td>0.185</td>
<td>0.275</td>
<td>1297</td>
</tr>
<tr>
<td>8 Oct.</td>
<td>209</td>
<td>0.164</td>
<td>0.196</td>
<td>0.297</td>
<td>1401</td>
</tr>
<tr>
<td>26 Nov.</td>
<td>258</td>
<td>0.179</td>
<td>0.209</td>
<td>0.325</td>
<td>1533</td>
</tr>
<tr>
<td>28 Jan., '55</td>
<td>321</td>
<td>0.186</td>
<td>0.215</td>
<td>0.338</td>
<td>1594</td>
</tr>
</tbody>
</table>
Table 30. Average strain in CW 4.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>Berry Gage Reading</th>
<th>Sum Total</th>
<th>Average</th>
<th>Dial Change</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 Mar., '54</td>
<td>2</td>
<td>0.009</td>
<td>0.009</td>
<td>No Force</td>
<td>0.019</td>
<td>90(Partial)</td>
</tr>
<tr>
<td>11 &quot;</td>
<td>2</td>
<td>0.022</td>
<td>0.015</td>
<td></td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td>12 &quot;</td>
<td>3</td>
<td>0.022</td>
<td>0.055</td>
<td>(Change of holes)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>15 &quot;</td>
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<td>0.147</td>
<td>0.220</td>
<td>1038</td>
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<td>1146</td>
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<td>0.139</td>
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<td>1057</td>
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<td>0.147</td>
<td>0.236</td>
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<tr>
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<td>0.174</td>
<td>0.269</td>
<td>1266</td>
<td></td>
</tr>
<tr>
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<td>0.187</td>
<td>0.293</td>
<td>1382</td>
<td></td>
</tr>
<tr>
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<td>1509</td>
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Table 31. Average strain in CW 5.

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<th>Age in Days</th>
<th>Berry Gage Reading</th>
<th>Sum Total Dial Change</th>
<th>Average Strain: $10^{-6}$ in/in</th>
</tr>
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<tbody>
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<td>Made No Force</td>
</tr>
<tr>
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<td>0.058</td>
<td>142 (Partial)</td>
</tr>
<tr>
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<td>2</td>
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<td>0.070</td>
<td>0.030</td>
</tr>
<tr>
<td>17 &quot;</td>
<td>7</td>
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<td>0.075</td>
<td>0.045</td>
</tr>
<tr>
<td>17 &quot;</td>
<td>7</td>
<td>0.155</td>
<td>0.101</td>
<td>0.132</td>
</tr>
<tr>
<td>20 &quot;</td>
<td>10</td>
<td>0.167</td>
<td>0.109</td>
<td>0.152</td>
</tr>
<tr>
<td>27 &quot;</td>
<td>17</td>
<td>0.168</td>
<td>0.134</td>
<td>0.178</td>
</tr>
<tr>
<td>3 April</td>
<td>24</td>
<td>0.083</td>
<td>0.121</td>
<td>0.080</td>
</tr>
<tr>
<td>10 &quot;</td>
<td>31</td>
<td>0.093</td>
<td>0.117</td>
<td>0.086</td>
</tr>
<tr>
<td>23 &quot;</td>
<td>44</td>
<td>0.101</td>
<td>0.123</td>
<td>0.100</td>
</tr>
<tr>
<td>6 May</td>
<td>57</td>
<td>0.110</td>
<td>0.135</td>
<td>0.121</td>
</tr>
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<td>0.138</td>
<td>0.132</td>
</tr>
<tr>
<td>29 June</td>
<td>111</td>
<td>0.121</td>
<td>0.140</td>
<td>0.137</td>
</tr>
<tr>
<td>28 July</td>
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<td>0.146</td>
<td>0.150</td>
</tr>
<tr>
<td>8 Oct.</td>
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<td>0.140</td>
<td>0.157</td>
<td>0.173</td>
</tr>
<tr>
<td>26 Nov.</td>
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<td>0.199</td>
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<tr>
<td>28 Jan., '55</td>
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<td>0.169</td>
<td>0.197</td>
</tr>
<tr>
<td>Date</td>
<td>Age in Days</td>
<td>Berry Gage Reading</td>
<td>Sum Total</td>
<td>Average Strain: $10^{-6}$ in/in.</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
<td>--------------------</td>
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<td>-------------------------------</td>
</tr>
<tr>
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<td>-</td>
<td>Made</td>
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<td>6 &quot;</td>
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<td>0.021</td>
<td>No Force</td>
</tr>
<tr>
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<td>0.044</td>
<td>0.046</td>
</tr>
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<td>18 &quot;</td>
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<td>0.051</td>
<td>0.060</td>
</tr>
<tr>
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<td>14</td>
<td>0.051</td>
<td>0.100</td>
<td>0.158</td>
</tr>
<tr>
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<td>0.081</td>
<td>0.120</td>
</tr>
<tr>
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<td>0.186</td>
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<td>29</td>
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<td>0.125</td>
<td>0.208</td>
</tr>
<tr>
<td>9 &quot;</td>
<td>36</td>
<td></td>
<td>0.132</td>
<td>0.222</td>
</tr>
<tr>
<td>15 &quot;</td>
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<td></td>
<td>0.132</td>
<td>0.222</td>
</tr>
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<td>58</td>
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<td>0.248</td>
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<td>0.150</td>
<td>0.258</td>
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<td>29 June</td>
<td>117</td>
<td></td>
<td>0.157</td>
<td>0.272</td>
</tr>
<tr>
<td>28 July</td>
<td>146</td>
<td></td>
<td>0.163</td>
<td>0.284</td>
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<tr>
<td>8 Oct.</td>
<td>218</td>
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<td>0.174</td>
<td>0.306</td>
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<tr>
<td>26 Nov.</td>
<td>267</td>
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<td>0.180</td>
<td>0.318</td>
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<td>28 Jan., '55</td>
<td>330</td>
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<td>0.336</td>
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</table>
Table 33. Average strain in CW 7.

<table>
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<th>Date</th>
<th>Age in Days</th>
<th>Berry Gauge Reading</th>
<th>Sum Total</th>
<th>Dial Change</th>
<th>Average Strain</th>
<th>Made</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>13</td>
<td>2</td>
<td>0.052</td>
<td>0.001</td>
<td>0.019</td>
<td>0.001</td>
<td>90(Partial)</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>0.066</td>
<td>0.006</td>
<td>0.019</td>
<td>0.006</td>
<td>203</td>
</tr>
<tr>
<td>20</td>
<td>9</td>
<td>0.075</td>
<td>0.021</td>
<td>0.043</td>
<td>0.021</td>
<td></td>
</tr>
<tr>
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<td>0.026</td>
<td>0.052</td>
<td>0.026</td>
<td>245</td>
</tr>
<tr>
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<td>21</td>
<td>0.114</td>
<td>0.076</td>
<td>0.137</td>
<td>0.076</td>
<td>646(Final)</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>0.120</td>
<td>0.089</td>
<td>0.156</td>
<td>0.089</td>
<td>736</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
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<td>0.097</td>
<td>0.167</td>
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<td>896</td>
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<td>0.118</td>
<td>0.210</td>
<td>0.118</td>
<td>991</td>
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<td>0.132</td>
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<td>0.158</td>
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<td>1156</td>
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<td>0.155</td>
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<td>0.170</td>
<td>1420</td>
</tr>
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<td>0.171</td>
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Table 34. Average strain in CW 8.

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<th>Sum Total</th>
<th>Average Strain (10^{-6}) in/in.</th>
<th>Made Force</th>
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<tbody>
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<td>-</td>
<td>-</td>
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<td>No Force</td>
</tr>
<tr>
<td>5 &quot;</td>
<td>2</td>
<td>0.000</td>
<td>0.032</td>
<td></td>
<td>127(Partial)</td>
</tr>
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<td>0.047</td>
<td>0.027</td>
<td>189</td>
</tr>
<tr>
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<td>0.026</td>
<td>0.046</td>
<td>0.040</td>
<td>307</td>
</tr>
<tr>
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<td>0.057</td>
<td>0.065</td>
<td>783</td>
</tr>
<tr>
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<td>28</td>
<td>0.043</td>
<td>0.155</td>
<td>0.166</td>
<td>1274(Final)</td>
</tr>
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<td>28</td>
<td>0.110</td>
<td>0.192</td>
<td>0.270</td>
<td>1274(Final)</td>
</tr>
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<td>2 April</td>
<td>30</td>
<td>0.115</td>
<td>0.210</td>
<td>0.293</td>
<td>1382</td>
</tr>
<tr>
<td>9 &quot;</td>
<td>37</td>
<td>0.120</td>
<td>0.217</td>
<td>0.305</td>
<td>1439</td>
</tr>
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<td>0.220</td>
<td>0.311</td>
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<td>0.241</td>
<td>0.350</td>
<td>1651</td>
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<td>0.146</td>
<td>0.249</td>
<td>0.363</td>
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</tr>
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<td>0.374</td>
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<td>0.158</td>
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<td>0.313</td>
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Table 35. Average strain in CW 9.

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<th>Berry Gage Reading</th>
<th>Sum Total</th>
<th>Average Strain: 10^-6 in/in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar., '54</td>
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<td>Made</td>
<td>-</td>
</tr>
<tr>
<td>13 &quot;</td>
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<td>0.026</td>
<td>No Force</td>
</tr>
<tr>
<td>13 &quot;</td>
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<td>0.090</td>
<td>0.112</td>
<td>0.156</td>
</tr>
<tr>
<td>15 &quot;</td>
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<td>0.098</td>
<td>0.128</td>
<td>0.180</td>
</tr>
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<td>23 &quot;</td>
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<td>0.110</td>
<td>0.154</td>
<td>0.218</td>
</tr>
<tr>
<td>31 &quot;</td>
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<tr>
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</tr>
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<td>0.176</td>
<td>0.256</td>
</tr>
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<td>0.294</td>
</tr>
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<td>0.194</td>
<td>0.285</td>
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<td>0.351</td>
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<tr>
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<td>0.142</td>
<td>0.369</td>
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<td>Jan., '55</td>
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</table>

"Made" and "Final" refer to final measurements.
Table 36. Average strain in CW 10.

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<th>Berrygage Reading</th>
<th>Sum Total Dial Change</th>
<th>Average Strain</th>
</tr>
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<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>31 &quot;</td>
<td>14</td>
<td>-0.130</td>
<td>-0.134</td>
<td>No Force</td>
</tr>
<tr>
<td>31 &quot;</td>
<td>14</td>
<td>-0.077</td>
<td>-0.080</td>
<td>0.107</td>
</tr>
<tr>
<td>2 April</td>
<td>16</td>
<td>0.026</td>
<td>0.030</td>
<td>0.320</td>
</tr>
<tr>
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<td>23</td>
<td>0.045</td>
<td>0.043</td>
<td>0.352</td>
</tr>
<tr>
<td>15 &quot;</td>
<td>29</td>
<td>0.047</td>
<td>0.045</td>
<td>0.356</td>
</tr>
<tr>
<td>23 &quot;</td>
<td>37</td>
<td>0.052</td>
<td>0.052</td>
<td>0.368</td>
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<tr>
<td>6 May</td>
<td>50</td>
<td>0.062</td>
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<td>0.388</td>
</tr>
<tr>
<td>29 &quot;</td>
<td>73</td>
<td>0.066</td>
<td>0.068</td>
<td>0.398</td>
</tr>
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<td>0.069</td>
<td>0.069</td>
<td>0.402</td>
</tr>
<tr>
<td>28 July</td>
<td>133</td>
<td>0.075</td>
<td>0.075</td>
<td>0.414</td>
</tr>
<tr>
<td>8 Oct.</td>
<td>205</td>
<td>0.085</td>
<td>0.085</td>
<td>0.434</td>
</tr>
<tr>
<td>26 Nov.</td>
<td>254</td>
<td>0.096</td>
<td>0.098</td>
<td>0.458</td>
</tr>
<tr>
<td>28 Jan., '55</td>
<td>317</td>
<td>0.095</td>
<td>0.097</td>
<td>0.456</td>
</tr>
</tbody>
</table>

*Made No Force 0.107. 505 (Final)*
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. 23. 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. 33. Ultimate prestress loss and ultimate strain after final prestress in CW 8 by Lorman Method.
Slope: 1.37
e_{ult}: 1470 micro in.

Slope: 0.286
S_{ult}: 28.0 percent
Conc: 309 psi
Steel: 37700 psi

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

\[ V = \frac{tS}{e} \]

Slope: 1.87
e_{ult}: 2090 micro in.

Slope: 0.380
S_{ult}: 38.0 percent
Conc: 410 psi
Steel: 50300 psi

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.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>Gage Dial 1</th>
<th>Gage Dial 2</th>
<th>Gross Strain $10^{-6}$ in/in.</th>
<th>Gage Dial 1</th>
<th>Gage Dial 2</th>
<th>Shrinkage Strain $10^{-6}$ in/in.</th>
<th>Creep Strain (Gross-Strain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 Oct., '53</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Made</td>
<td>--</td>
</tr>
<tr>
<td>24 &quot;</td>
<td>2</td>
<td>0.550</td>
<td>0.879</td>
<td>--</td>
<td>400</td>
<td>697</td>
<td>No Force</td>
<td>--</td>
</tr>
<tr>
<td>24 &quot;</td>
<td>2</td>
<td>0.610</td>
<td>0.937</td>
<td>134 (Instantaneous elastic strain)</td>
<td>--</td>
<td>--</td>
<td>Partial</td>
<td>--</td>
</tr>
<tr>
<td>26 &quot;</td>
<td>4</td>
<td>0.650</td>
<td>0.968</td>
<td>80</td>
<td>429</td>
<td>710</td>
<td>47</td>
<td>37</td>
</tr>
<tr>
<td>26 &quot;</td>
<td>4</td>
<td>0.829</td>
<td>1.139</td>
<td>396 (Instantaneous elastic strain)</td>
<td>--</td>
<td>--</td>
<td>Final</td>
<td>--</td>
</tr>
<tr>
<td>2 Nov.</td>
<td>11</td>
<td>0.959</td>
<td>1.252</td>
<td>355</td>
<td>449</td>
<td>790</td>
<td>160</td>
<td>195</td>
</tr>
<tr>
<td>9 &quot;</td>
<td>18</td>
<td>1.028</td>
<td>1.330</td>
<td>522</td>
<td>519</td>
<td>818</td>
<td>271</td>
<td>251</td>
</tr>
<tr>
<td>23 &quot;</td>
<td>32</td>
<td>1.110</td>
<td>1.410</td>
<td>705</td>
<td>560</td>
<td>891</td>
<td>400</td>
<td>305</td>
</tr>
<tr>
<td>14 Dec.</td>
<td>53</td>
<td>1.190</td>
<td>1.490</td>
<td>886</td>
<td>630</td>
<td>960</td>
<td>558</td>
<td>328</td>
</tr>
<tr>
<td>11 Jan., '54</td>
<td>81</td>
<td>1.260</td>
<td>1.551</td>
<td>1034</td>
<td>670</td>
<td>1002</td>
<td>650</td>
<td>384</td>
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<tr>
<td>8 Feb.</td>
<td>109</td>
<td>1.271</td>
<td>1.580</td>
<td>1079</td>
<td>671</td>
<td>1010</td>
<td>660</td>
<td>420</td>
</tr>
<tr>
<td>8 Mar.</td>
<td>137</td>
<td>1.320</td>
<td>1.620</td>
<td>1180</td>
<td>702</td>
<td>1031</td>
<td>719</td>
<td>461</td>
</tr>
<tr>
<td>5 Apr.</td>
<td>165</td>
<td>1.348</td>
<td>1.650</td>
<td>1246</td>
<td>721</td>
<td>1050</td>
<td>762</td>
<td>484</td>
</tr>
<tr>
<td>3 May</td>
<td>193</td>
<td>1.349</td>
<td>1.650</td>
<td>1247</td>
<td>700</td>
<td>1029</td>
<td>715</td>
<td>532</td>
</tr>
<tr>
<td>31 &quot;</td>
<td>221</td>
<td>1.325</td>
<td>1.630</td>
<td>1198</td>
<td>680</td>
<td>1010</td>
<td>671</td>
<td>527</td>
</tr>
<tr>
<td>28 June</td>
<td>249</td>
<td>1.330</td>
<td>1.620</td>
<td>1192</td>
<td>691</td>
<td>991</td>
<td>661</td>
<td>541</td>
</tr>
<tr>
<td>13 July</td>
<td>264</td>
<td>1.350</td>
<td>1.630</td>
<td>1226</td>
<td>700</td>
<td>1011</td>
<td>694</td>
<td>542</td>
</tr>
<tr>
<td>13 &quot; Placed in water tank for further testing.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Age in Days</td>
<td>E Gage Dial</td>
<td>Gross Strain $10^{-6}$ in/in</td>
<td>F Gage Dial</td>
<td>Shrinkage Strain $10^{-6}$ in/in</td>
<td>Creep Strain (Gross-Shrinkage)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
<td>-------------</td>
<td>------------------</td>
<td>-------------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22 Oct., '53</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 &quot;</td>
<td>2</td>
<td>0.538</td>
<td>0.588</td>
<td>---</td>
<td>578</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 &quot;</td>
<td>2</td>
<td>0.588</td>
<td>0.648</td>
<td>110</td>
<td>(Instantaneous elastic strain)</td>
<td>No Force</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26 &quot;</td>
<td>4</td>
<td>0.629</td>
<td>0.699</td>
<td>104</td>
<td>610</td>
<td>509</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 &quot;</td>
<td>7</td>
<td>0.659</td>
<td>0.730</td>
<td>173</td>
<td>620</td>
<td>549</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 &quot;</td>
<td>7</td>
<td>0.808</td>
<td>0.909</td>
<td>372</td>
<td>(Instantaneous elastic strain)</td>
<td>Final</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Nov.</td>
<td>14</td>
<td>0.920</td>
<td>1.029</td>
<td>435</td>
<td>650</td>
<td>600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 &quot;</td>
<td>21</td>
<td>0.959</td>
<td>1.071</td>
<td>527</td>
<td>698</td>
<td>629</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26 &quot;</td>
<td>35</td>
<td>1.030</td>
<td>1.150</td>
<td>596</td>
<td>758</td>
<td>671</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Dec.</td>
<td>56</td>
<td>1.103</td>
<td>1.240</td>
<td>882</td>
<td>821</td>
<td>731</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Jan., '54</td>
<td>84</td>
<td>1.148</td>
<td>1.292</td>
<td>991</td>
<td>850</td>
<td>760</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Feb.</td>
<td>112</td>
<td>1.170</td>
<td>1.329</td>
<td>1058</td>
<td>870</td>
<td>780</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Mar.</td>
<td>140</td>
<td>1.201</td>
<td>1.351</td>
<td>1119</td>
<td>890</td>
<td>801</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 April</td>
<td>168</td>
<td>1.212</td>
<td>1.370</td>
<td>1153</td>
<td>890</td>
<td>801</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 May</td>
<td>196</td>
<td>1.235</td>
<td>1.380</td>
<td>1190</td>
<td>900</td>
<td>810</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 June</td>
<td>224</td>
<td>1.230</td>
<td>1.377</td>
<td>1181</td>
<td>890</td>
<td>790</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 July</td>
<td>252</td>
<td>1.220</td>
<td>1.370</td>
<td>1161</td>
<td>880</td>
<td>780</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 &quot;</td>
<td>265</td>
<td>1.220</td>
<td>1.360</td>
<td>1150</td>
<td>880</td>
<td>780</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Placed in water tank for further testing.*
Table 39. Shrinkage, creep and gross strain in CW 7 control beam.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>E: Gage Dial</th>
<th>Gross Strain:</th>
<th>F: Gage Dial</th>
<th>Shrinkage:</th>
<th>G: Gage Dial</th>
<th>Shrinkage:</th>
<th>Strain: (Gross - Shrink)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 Oct., '53</td>
<td>0</td>
<td>0.400</td>
<td>0.309 -</td>
<td>0.439</td>
<td>0.690 -</td>
<td>0.219</td>
<td>0.421</td>
<td>Made No Force Partial -</td>
</tr>
<tr>
<td>15 &quot;</td>
<td>2</td>
<td>0.480</td>
<td>0.360</td>
<td>148</td>
<td>(Instantaneous elastic strain)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 &quot;</td>
<td>7</td>
<td>0.549</td>
<td>0.412</td>
<td>137</td>
<td>0.490</td>
<td>0.712 82</td>
<td>0.270 0.441</td>
<td>80 56</td>
</tr>
<tr>
<td>27 &quot;</td>
<td>14</td>
<td>0.609</td>
<td>0.470</td>
<td>271</td>
<td>0.540</td>
<td>0.740 171</td>
<td>0.330 0.461</td>
<td>171 100</td>
</tr>
<tr>
<td>3 Nov.</td>
<td>21</td>
<td>0.640</td>
<td>0.500</td>
<td>340</td>
<td>0.539</td>
<td>0.801 239</td>
<td>0.320 0.529</td>
<td>237 102</td>
</tr>
<tr>
<td>10 &quot;</td>
<td>28</td>
<td>0.860</td>
<td>0.652</td>
<td>467</td>
<td>0.550</td>
<td>0.830 284</td>
<td>0.349 0.548</td>
<td>292 179</td>
</tr>
<tr>
<td>24 &quot;</td>
<td>42</td>
<td>0.940</td>
<td>0.711</td>
<td>624</td>
<td>0.608</td>
<td>0.860 374</td>
<td>0.398 0.580</td>
<td>383 241</td>
</tr>
<tr>
<td>15 Dec.</td>
<td>63</td>
<td>1.028</td>
<td>0.780</td>
<td>802</td>
<td>0.660</td>
<td>0.922 513</td>
<td>0.450 0.642</td>
<td>512 290</td>
</tr>
<tr>
<td>12 Jan., '54</td>
<td>91</td>
<td>1.091</td>
<td>0.840</td>
<td>941</td>
<td>0.720</td>
<td>0.970 635</td>
<td>0.501 0.700</td>
<td>635 306</td>
</tr>
<tr>
<td>9 Feb.</td>
<td>111</td>
<td>1.120</td>
<td>0.852</td>
<td>937</td>
<td>0.721</td>
<td>0.980 648</td>
<td>0.510 0.709</td>
<td>656 335</td>
</tr>
<tr>
<td>9 Mar.</td>
<td>147</td>
<td>1.170</td>
<td>0.909</td>
<td>1109</td>
<td>0.757</td>
<td>1.021 745</td>
<td>0.548 0.743</td>
<td>744 369</td>
</tr>
<tr>
<td>6 Apr.</td>
<td>175</td>
<td>1.170</td>
<td>0.911</td>
<td>1110</td>
<td>0.750</td>
<td>1.021 727</td>
<td>0.540 0.749</td>
<td>735 380</td>
</tr>
<tr>
<td>4 May</td>
<td>203</td>
<td>1.230</td>
<td>0.960</td>
<td>1234</td>
<td>0.782</td>
<td>1.050 796</td>
<td>0.580 0.780</td>
<td>814 429</td>
</tr>
<tr>
<td>28 June</td>
<td>231</td>
<td>1.180</td>
<td>0.930</td>
<td>1144</td>
<td>0.730</td>
<td>1.002 683</td>
<td>0.520 0.730</td>
<td>691 457</td>
</tr>
<tr>
<td>13 July</td>
<td>246</td>
<td>1.200</td>
<td>0.930</td>
<td>1167</td>
<td>0.760</td>
<td>1.020 737</td>
<td>0.540 0.730</td>
<td>714 441</td>
</tr>
</tbody>
</table>

Placed in water tank to soak for further testing.
Table 40. Shrinkage, creep and gross strain of CW 9 control beam.

<table>
<thead>
<tr>
<th>Date</th>
<th>Age in Days</th>
<th>E Gage Dial</th>
<th>Gross Strain</th>
<th>F Gage Dial</th>
<th>Shrinkage</th>
<th>G Gage Dial</th>
<th>Creep Strain</th>
<th>Made</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 Oct., '53</td>
<td>0</td>
<td>0.419</td>
<td>0.489</td>
<td>-</td>
<td>0.490</td>
<td>0.210</td>
<td>-</td>
<td>No Force</td>
</tr>
<tr>
<td>15 &quot;</td>
<td>2</td>
<td>0.461</td>
<td>0.520</td>
<td>-</td>
<td>0.529</td>
<td>0.228</td>
<td>-</td>
<td>No Force</td>
</tr>
<tr>
<td>20 &quot;</td>
<td>7</td>
<td>0.630</td>
<td>0.763</td>
<td>466 (Instantaneous elastic strain)</td>
<td>0.580</td>
<td>0.240</td>
<td>71</td>
<td>Final</td>
</tr>
<tr>
<td>27 &quot;</td>
<td>14</td>
<td>0.739</td>
<td>0.929</td>
<td>311</td>
<td>0.520</td>
<td>0.519</td>
<td>88 231</td>
<td>-</td>
</tr>
<tr>
<td>10 Nov.</td>
<td>28</td>
<td>0.818</td>
<td>1.030</td>
<td>515</td>
<td>0.609</td>
<td>0.339</td>
<td>216 214 300</td>
<td>-</td>
</tr>
<tr>
<td>1 Dec.</td>
<td>49</td>
<td>0.909</td>
<td>1.129</td>
<td>730</td>
<td>0.679</td>
<td>0.396</td>
<td>360 360 370</td>
<td>-</td>
</tr>
<tr>
<td>29 &quot;</td>
<td>77</td>
<td>0.972</td>
<td>1.220</td>
<td>905</td>
<td>0.731</td>
<td>0.441</td>
<td>470 485 428</td>
<td>-</td>
</tr>
<tr>
<td>26 Jan., '54</td>
<td>105</td>
<td>1.020</td>
<td>1.260</td>
<td>1005</td>
<td>0.756</td>
<td>0.470</td>
<td>531 549 465</td>
<td>-</td>
</tr>
<tr>
<td>23 Feb.</td>
<td>133</td>
<td>1.051</td>
<td>1.301</td>
<td>1086</td>
<td>0.777</td>
<td>0.488</td>
<td>575 585 506</td>
<td>-</td>
</tr>
<tr>
<td>23 Mar.</td>
<td>161</td>
<td>1.079</td>
<td>1.330</td>
<td>1151</td>
<td>0.792</td>
<td>0.511</td>
<td>619 635 524</td>
<td>-</td>
</tr>
<tr>
<td>20 Apr.</td>
<td>189</td>
<td>1.090</td>
<td>1.360</td>
<td>1197</td>
<td>0.800</td>
<td>0.520</td>
<td>637 656 550</td>
<td>-</td>
</tr>
<tr>
<td>18 May</td>
<td>217</td>
<td>1.080</td>
<td>1.350</td>
<td>1175</td>
<td>0.786</td>
<td>0.507</td>
<td>607 611 566</td>
<td>-</td>
</tr>
<tr>
<td>15 June</td>
<td>245</td>
<td>1.057</td>
<td>1.325</td>
<td>1120</td>
<td>0.756</td>
<td>0.469</td>
<td>530 438 636</td>
<td>-</td>
</tr>
<tr>
<td>13 July</td>
<td>273</td>
<td>1.080</td>
<td>1.360</td>
<td>1186</td>
<td>0.770</td>
<td>0.490</td>
<td>569 589 607</td>
<td>-</td>
</tr>
</tbody>
</table>

13 " Placed in water tank for further testing.
THE EFFECTS OF PARTIAL PRESTRESSING ON NEWLY CAST HAYDITE BEAMS

by

JOHN DeWITT RIDDELL

S. B., Massachusetts Institute of Technology, 1953

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Applied Mechanics

KANSAS STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE

1955
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 152,000 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=313 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.
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