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Test of a 70 foot prestressed-pretensioned concrete beam

Carl E., Ekberg Jr.

TEST OF A 70 FOOT PRESTRESSED-PRETENSIONED CONCRETE BEAM

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REPORT ON
70 FT BEAM TEST
for
Concrete Products Company of America

(A Division of American-Marietta Company of Pennsylvania)

Test Conducted by

Fritz Engineering Laboratory

(Under the Auspices of the Institute of Research)

Lehigh University

Bethlehem, Penna.

Submitted by: ______________________

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Associate Professor of Civil Engineering

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Date Submitted: September 1, 1956

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This report covers the most significant features of a static test on a 70 ft prestressed concrete bridge beam. Shortly after the 70 ft beam was tested, a similar beam of 55 ft length was brought to the laboratory and subjected to over three million cycles of repetitive loading. A second report on the 55 ft beam will give a basis for comparison between the behavior of the 70 ft beam under static test and the second beam under repetitive loading.

The test was sponsored by the Concrete Products Company of America (a Division of the American Marietta Company of Pennsylvania). The beam used is commercially available under the trade name of "AMDEK".

OBJECTIVES

The original objectives of the test program were two-fold: first, to determine the feasibility of a rectangular box section for long-span bridge members; and secondly, to compare the static behavior of the 70 ft. beam with the dynamic behavior of the 55 ft beam.

DESCRIPTION OF THE BEAM

The beam was of pretensioned bonded design having overall dimensions of 70 ft in length, 36 in. in width and

33 in. in depth. Rectangular hollows pass the full length except for two ft solid portions at the ends and at midspan. The prestressing tendons consist of 46 strands of 3/8 in. diam lying in a horizontal trajectory, and stressed initially to 150,000 psi. The conventional reinforcing steel consisted of inverted U-shaped No. 4 bars and four longitudinal No. 6 bars. The No. 4 bars were spaced at 8 in. centers and acted in a dual role as stirrups and as transverse flexure reinforcing for the top side of the section. The longitudinal bars likewise functioned in a dual role, as they passed the full length of the beam near the top fiber and served to minimize the opening of shrinkage cracks as well as to tie the system of U-shaped rods into one easily handled unit. An elevation view and cross-section are shown in Figure 1.

Design

The design of the beam is based on the specifications of the Pennsylvania Department of Highways. An analysis of the beam is given in Appendix A and summarized in Table 1. The analysis was patterned after the design calculations submitted by the manufacturer.

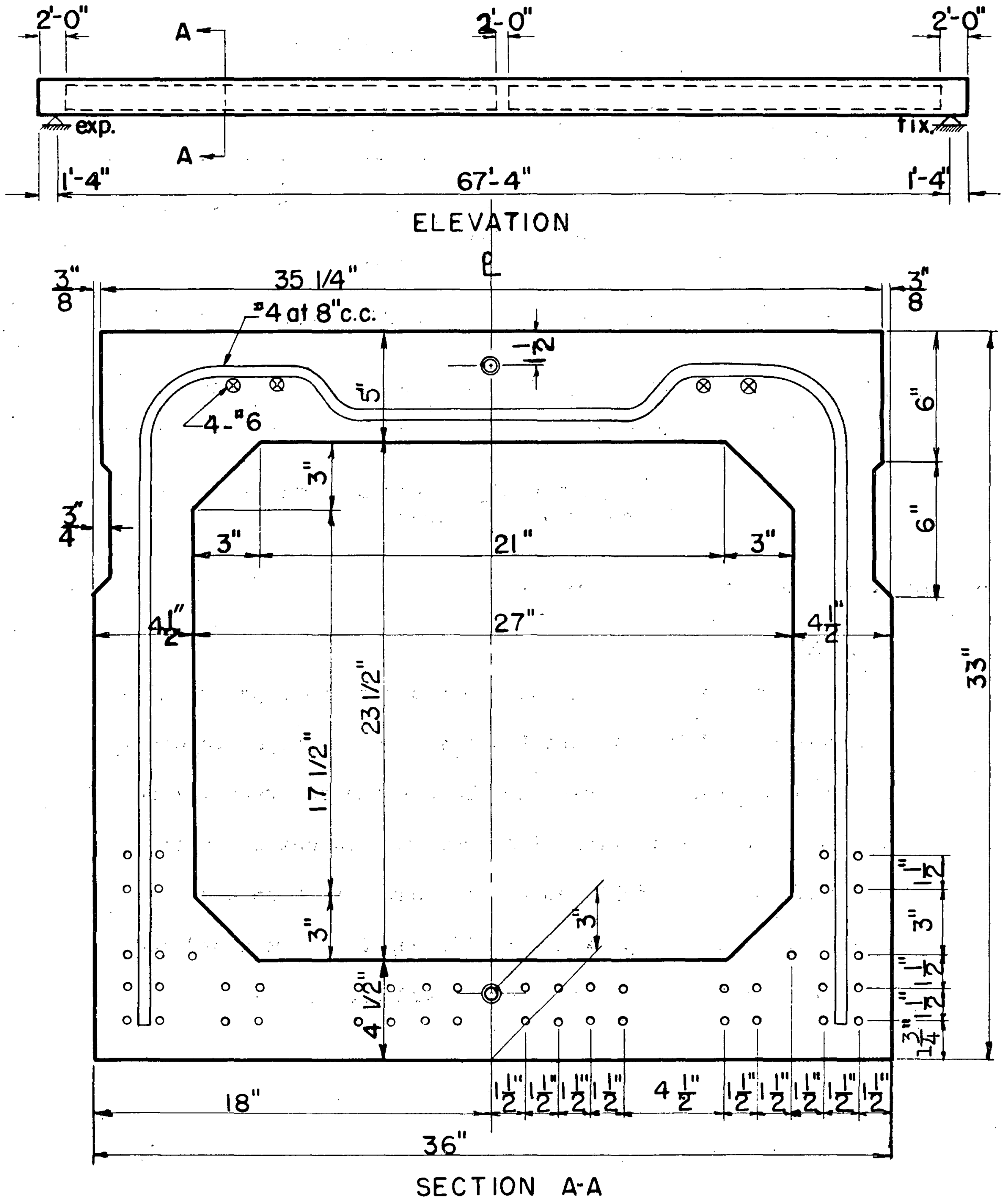


Fig. 1 - TEST BEAM

Table 1 - Summary of Design Calculations

Column	1	2	3	4	5	6	7	8
	P initial psi	P final psi	D.L. Beam	D.L. Surface	L.L. + Impact	1+3	2+3	4+5+7
Top Fiber	+473	+379	-901	-128	-887	-428	-522	-1537
Bottom Fiber	-2458	-1966	+905	+128	+891	-1553	-1061	-42

Note: The negative sign denotes compression, and the positive sign tension.

Materials

Concrete

The concrete was mixed in a one cu yd capacity mixer and was poured in a 25 deg F atmosphere. A high frequency internal vibrator was used to compact the concrete in the forms before application of a 30-minute vacuum treatment. The vacuuming was followed by five days of steam curing at a temperature of approximately 125 deg F. The mix had the following proportions on a cubic yard basis:

Cement - Type I(a) - 9 sacks
Wet Sand - (5% surface moisture) - 1239 pounds
Crushed Rock - (1% surface moisture) - 1876 pounds
Water - 27 gallons
Water:Cement - 4.06 gallons per sack.

Steel

The steel strand had a nominal diameter of 3/8 in. with an ultimate tensile strength of 250,000 psi. Each strand was tensioned individually by a calibrated hydraulic jack to a stress of 150,000 psi.

Manufacture

The beam was manufactured at the Pottstown, Pennsylvania plant of the Concrete Products Company of America on a prestressing bed of 125 ft in length. A second beam of 55 ft length was poured on the same bed with a cross-section identical to that of the 70 ft. beam. The entire pouring operation was continuous and required a total of about three and one-half hours for both beams.

The schedule of manufacture is shown in Table 2.

Table 2 - Manufacturing Schedule for the Beams

Event	Date
46 strands tensioned to 150,000 psi	Jan. 24
Concrete placed	Jan. 25 (2 hr.)
Vacuum process	Jan. 25 (30 min.)
Steam curing at 125 deg F	Jan. 25 - Jan. 30
Release of prestress	Jan. 30
Removal from bed	Jan. 31
Storage in plant at outside temp	Jan. 31 - Feb. 20
Removal to Fritz Engineering Laboratory for testing	Feb. 20

TEST PROGRAM

Pottstown Plant

The testing at the plant was conducted so as not to interfere with normal plant operation. The test work included the measurement of camber, total beam shortening, slip of strands at release of prestress, strains on the concrete, and strand stress.

Fritz Engineering Laboratory

The test work in the Laboratory involved the static loading of the beam near the third points with measurement of corresponding vertical deflections, total shortening of upper fibers, total lengthening of lower fibers, strains on the concrete as determined by both Whittemore and SR-4 gages, and crack patterns.

TESTING PROCEDURE AND TEST RESULTS

Pottstown Plant

Camber

The camber readings were taken by means of a precise level using calibrated scales mounted on the beam as targets. A total of five scales were placed on the beam using one at each end, one at center, and one at each quarter point.

Figure 2 shows the relationship between the camber and time after full release of prestress. It was unfortunate that due to unforeseen difficulty in using the level in the plant camber readings beyond the first day after release were not obtained. The maximum camber after 22 hours is seen to be 0.6 in.

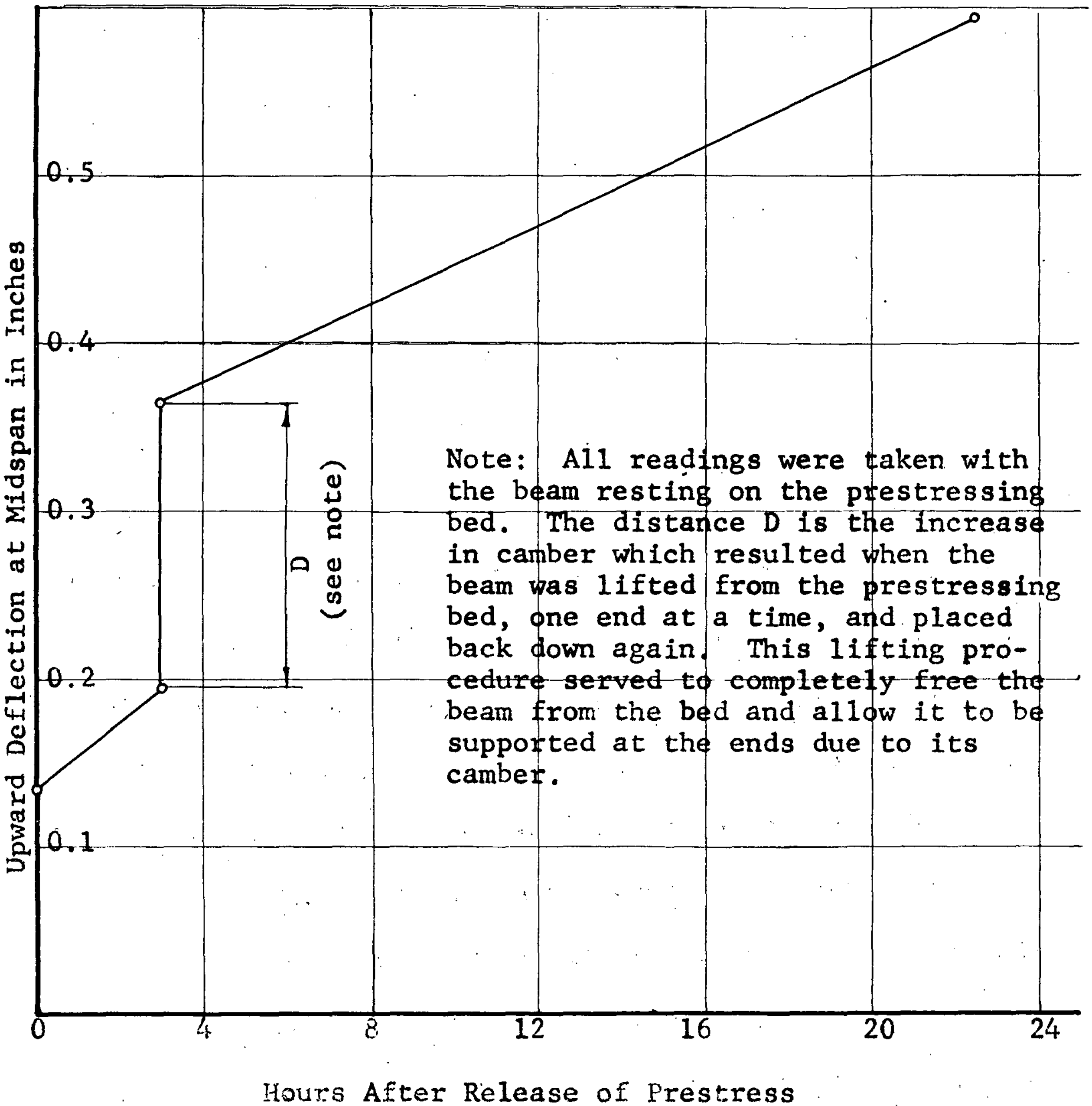


Fig. 2 - Camber Due to Dead Load Plus Prestress

Total Shortening

The total shortening of the beam upon release of prestress was measured near the top and bottom sides. This was achieved by inserting longitudinally two 1/2 in. steel pipes into the concrete with one located 1-1/2 in. below the top surface of the beam at its center and the other located 3 in. above the bottom surface of the beam at its center (see Fig. 1). Into each pipe a 5/16 in. round greased rod, 70 ft long, was placed. Ames Dial indicators were independently mounted to the concrete on each end of the rods. The total change in length of fibers of the beam at these levels was thus indicated by a change in the readings of the dials.

Figure 3 shows the 5/16 in. rods projecting from one end of the beam near the top and bottom. It will be noted that the Ames Dial at the top is mounted on a steel rod which has been set firmly into a drilled hole in the concrete at the same level as the pipe. The lower Ames Dial is simply mounted directly to the pipe itself which is seen to project slightly from the concrete. The 5/16 in. rods were lubricated to such a degree that they could easily be pushed back and forth with the fingertips.

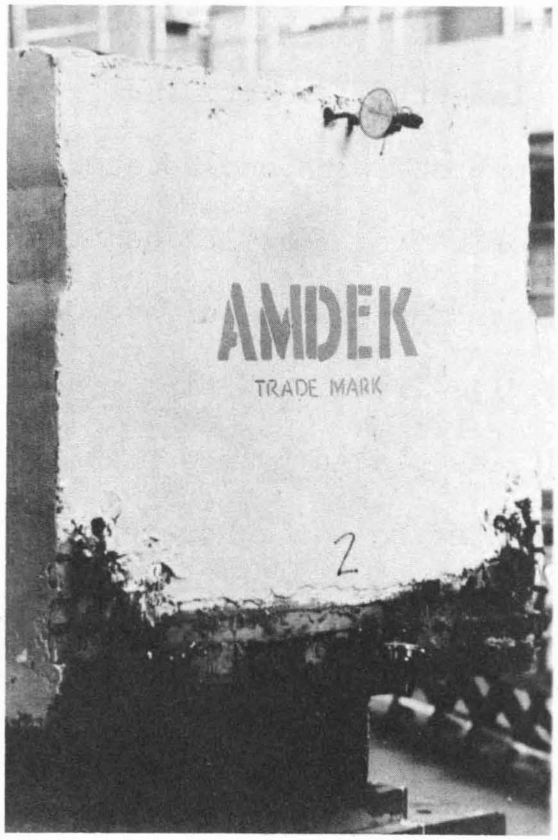


Fig. 3 - End View of Beam Showing Dials for Total Shortening

Figure 4 shows the total shortening after release of prestress over a period of 20 hours. It is surprising to note that the fiber $\overline{PQ}$ near the top of the beam shortened about half as much as the fiber $\overline{RS}$ near the bottom. Actually, if the beam had performed at this stage as a perfectly elastic and homogeneous body the fiber $\overline{PQ}$ should have shortened to a much lesser extent. The large amount of shortening along $\overline{PQ}$ suggests the possibility that there was a number of minute cracks in the top fiber, and these were closed upon release of prestress.

The loss of prestress may be approximated from the total shortening along $\overline{RS}$ (See Fig. 4) as follows:

$$\sigma = \frac{\Delta_s E}{L} = \frac{0.29 \times 30{,}000{,}000}{70 \times 12} = 10{,}350 \text{ psi}$$

where σ is the average loss of prestress in the steel in psi, Δ_s is the shortening at the centroid of the steel in inches, E is the Young's Modulus for the steel strand in psi, and L is the length of the beam in inches.

<u>Slip of Strands at Release</u>

The movement into the concrete of the strands upon release of prestress was measured at one end of the beam only. In this case, four strands were selected because of space limitations; however, it is believed that typical values were obtained. The slip was measured by means of Ames Dials mounted on the strand with stems bearing

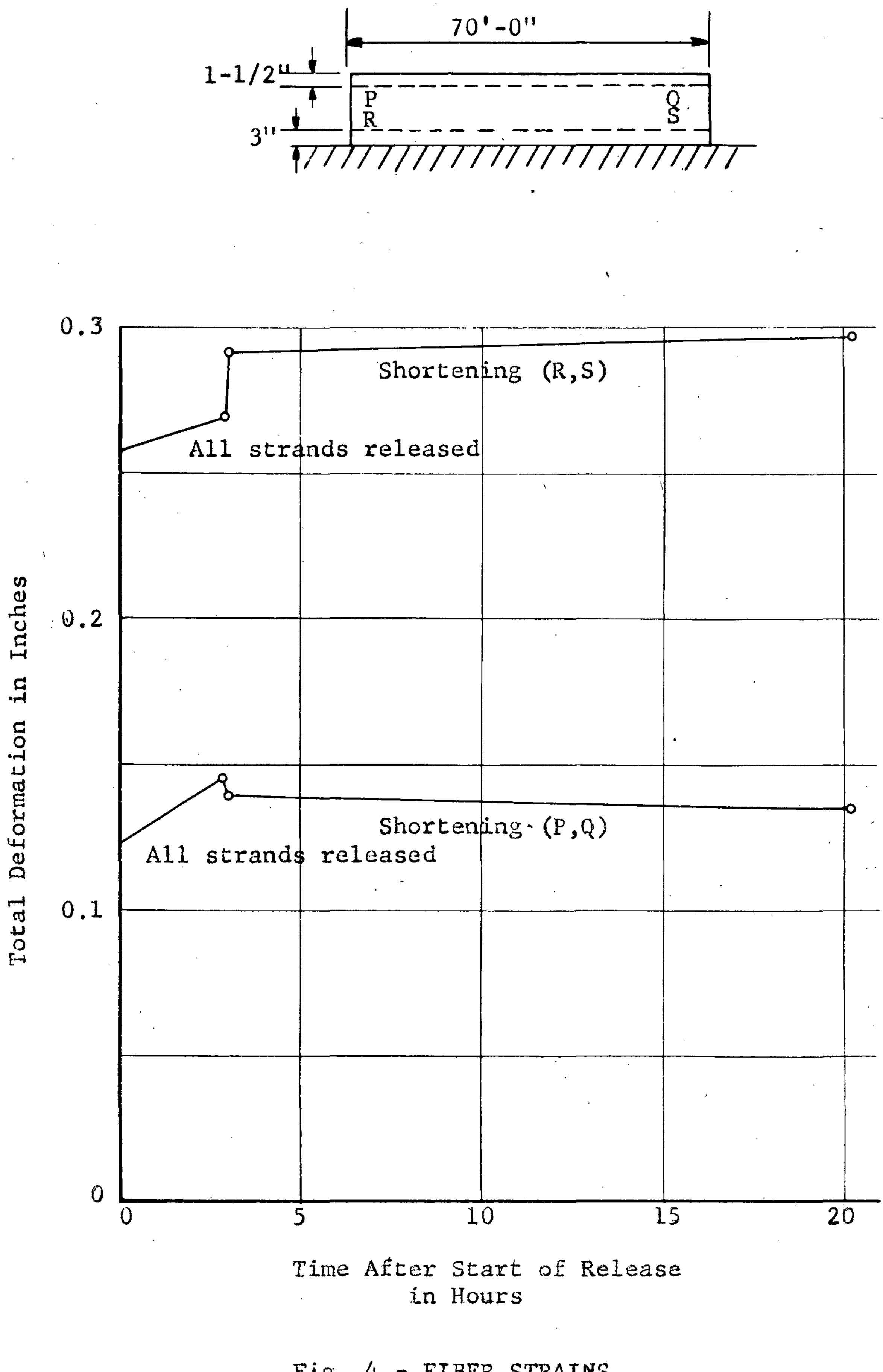


Fig. 4 - FIBER STRAINS

against the concrete. Thus, any strand movement into the concrete was directly measured upon release of prestress.

The dials for measuring slip are shown in Fig. 5.

The slip values for each of the four strands measured are 0.085 in., 0.058 in., 0.056 in., 0.079 in.; or an average of 0.070 in. These results are about the same as have been obtained in the Laboratory in numerous tests which have been conducted during the past two years.

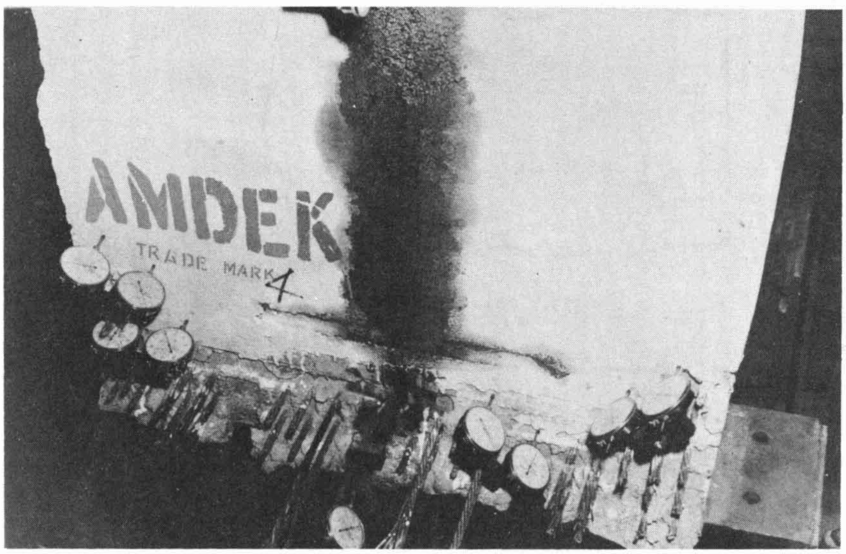


Fig. 5 - End View of Beam Showing the Dials for Measuring Slip of Strand at Release of Prestress

<u>Whittemore Strain Readings</u>

Strain measurements were taken on the concrete at various points by means of a Whittemore gage using a 10 in. gage length. Figure 6 indicates the locations on the beam

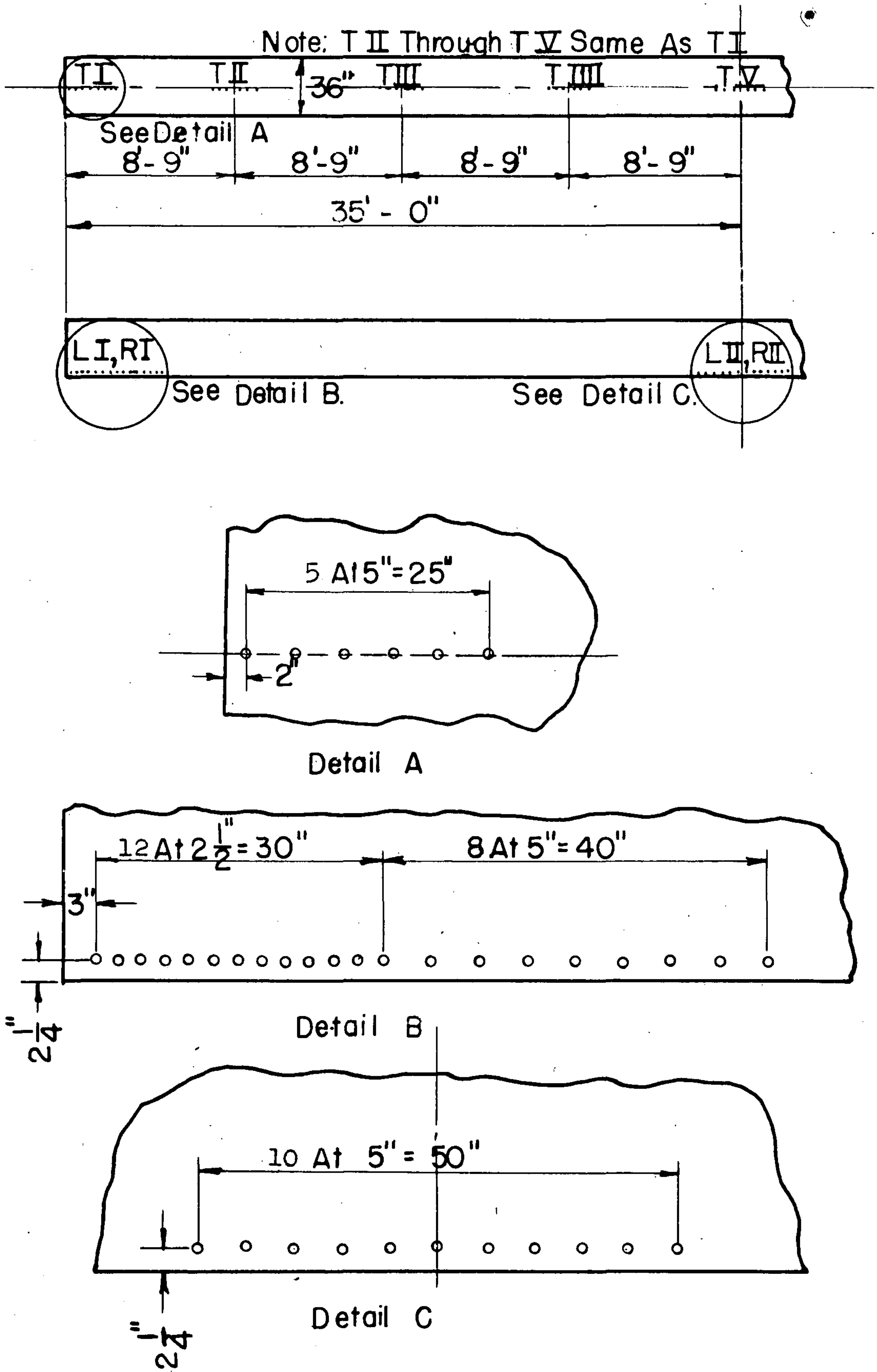


Fig. 6 Whittemore Plug Location

where these measurements were taken. One group of readings, designated TI through TV inclusive, were taken along the top fiber of the concrete in a longitudinal direction at the center. Another set of readings were taken along each side of the beam at the level of the strands and these were designated LI and LII on one side and RI and RII on the opposite side.

Figure 7 shows the results of all measurements, both in the plant and at the laboratory, however, only the measurements made in the plant will be discussed at this point. The upper group of curves are the results of measurements taken on the Whittemore plugs on the top fiber, and the curve labeled "0" depicts the strains measured at the plant shortly after release of prestress and at one day later. It is interesting to note that there is no apparent tension in the top fiber at the ends of the beam, which is contradictory to the theory. The curves labeled "1" and "2" in the lower group show the development of strain in the concrete at the level of the strands as the distance from the end of the beam increases at different times as designated. The curves shown are the averages of

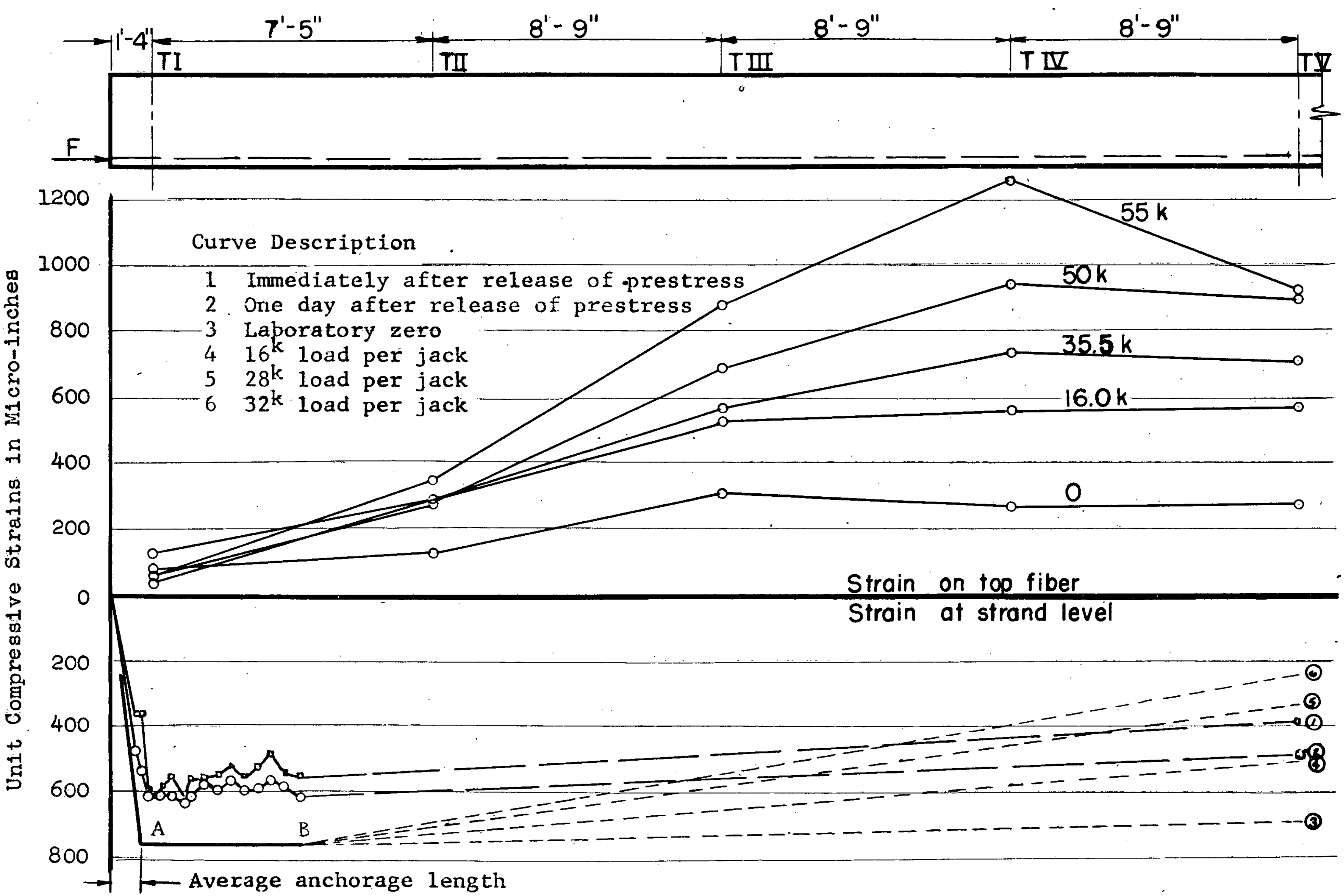


Fig. 7 - ANCHORAGE LENGTH AND FIBER STRAINS

two sets of readings on opposite sides of the beam and indicates the full development of prestress at a distance of approximately 16 in. from the end of the beam.

Strand Stress

Strand stress was measured by four electrical strand dynamometers inserted approximately at midspan (see Fig. 8).

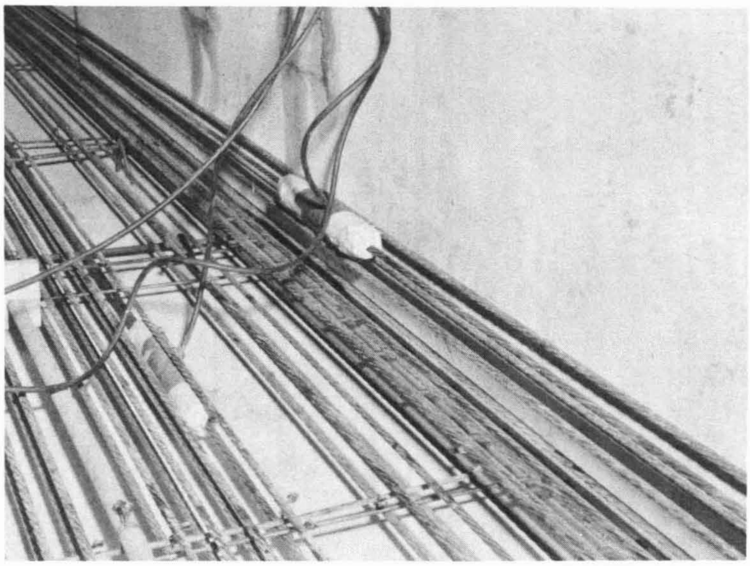


Fig. 8 - View of Strand Dynamometer

These dynamometers consisted of two threaded strand vises and a machined calibrated coupling with electrical strain gages attached. Figure 9 shows the details of the device.

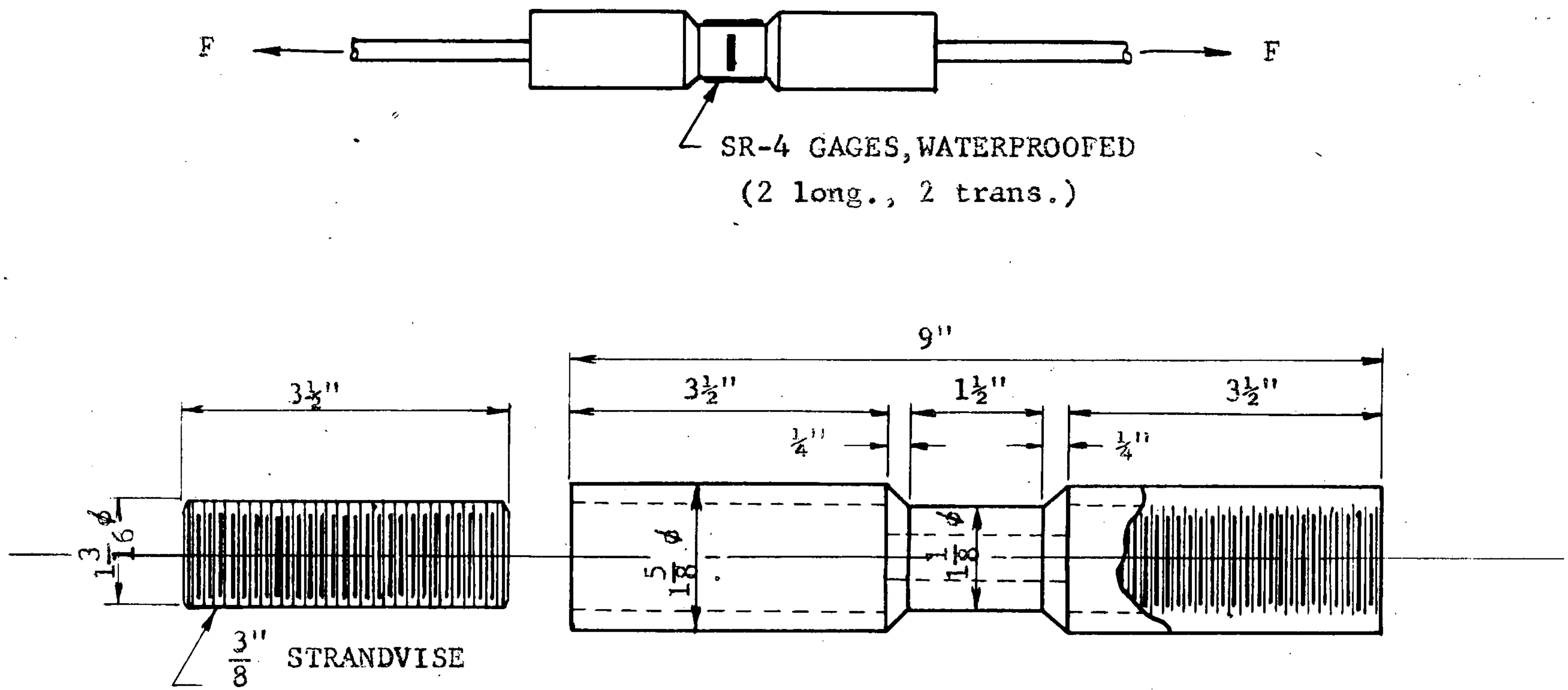


FIG. 9 - DETAILS OF STRAND DYNAMOMETER

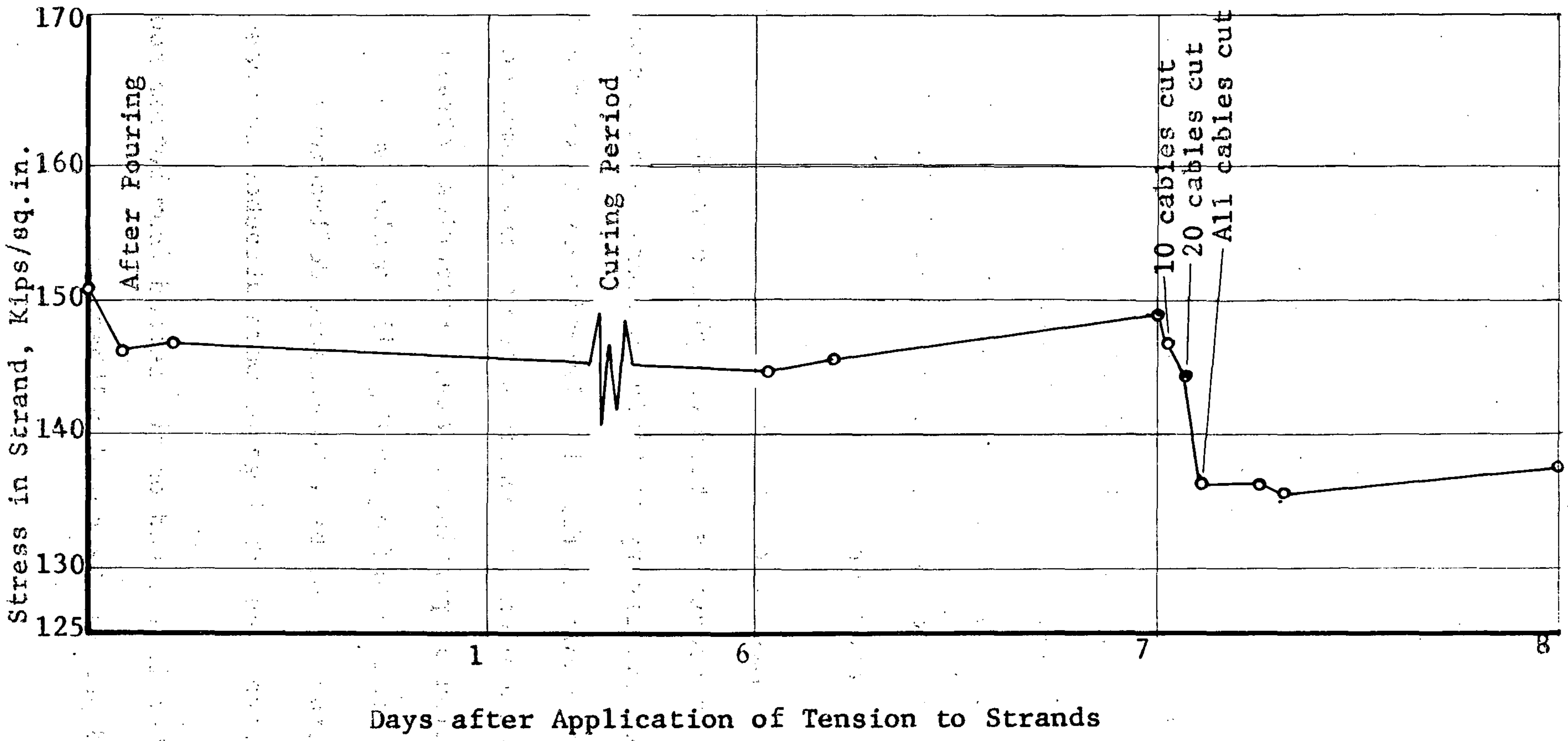


FIG. 10 - LOSS OF INITIAL PRESTRESS

Fig. 10 shows the important relation of prestress, as measured by one of the dynamometers, vs. time from the pouring of the beam to the eighth day after pouring.* Note the initial and final values of the stress per strand. These values indicate a prestress loss of only 9.1 per cent due to elastic shortening, only approximately one half the percentage of loss assumed in the design. There will be additional loss of prestress caused by subsequent shrinkage and creep of the concrete, however. Unfortunately, the strand dynamometers did not function properly during the load tests in the laboratory.

Laboratory Testing

The 70 ft pretensioned beam was placed on simple supports at Fritz Laboratory of Lehigh University on a span of 67 ft 4 in. as shown in Fig. 1. Immediately after the placing of the beam upon its bearings it was instrumented for the acquisition of pertinent data. Electrical strain gages were installed according to Fig. 11, scales were mounted on the side of the beam to measure deflections with a precise level, and dial gages were attached to measure

* This dynamometer is located on the second from bottom row of strands at midspan in the solid bulkhead.

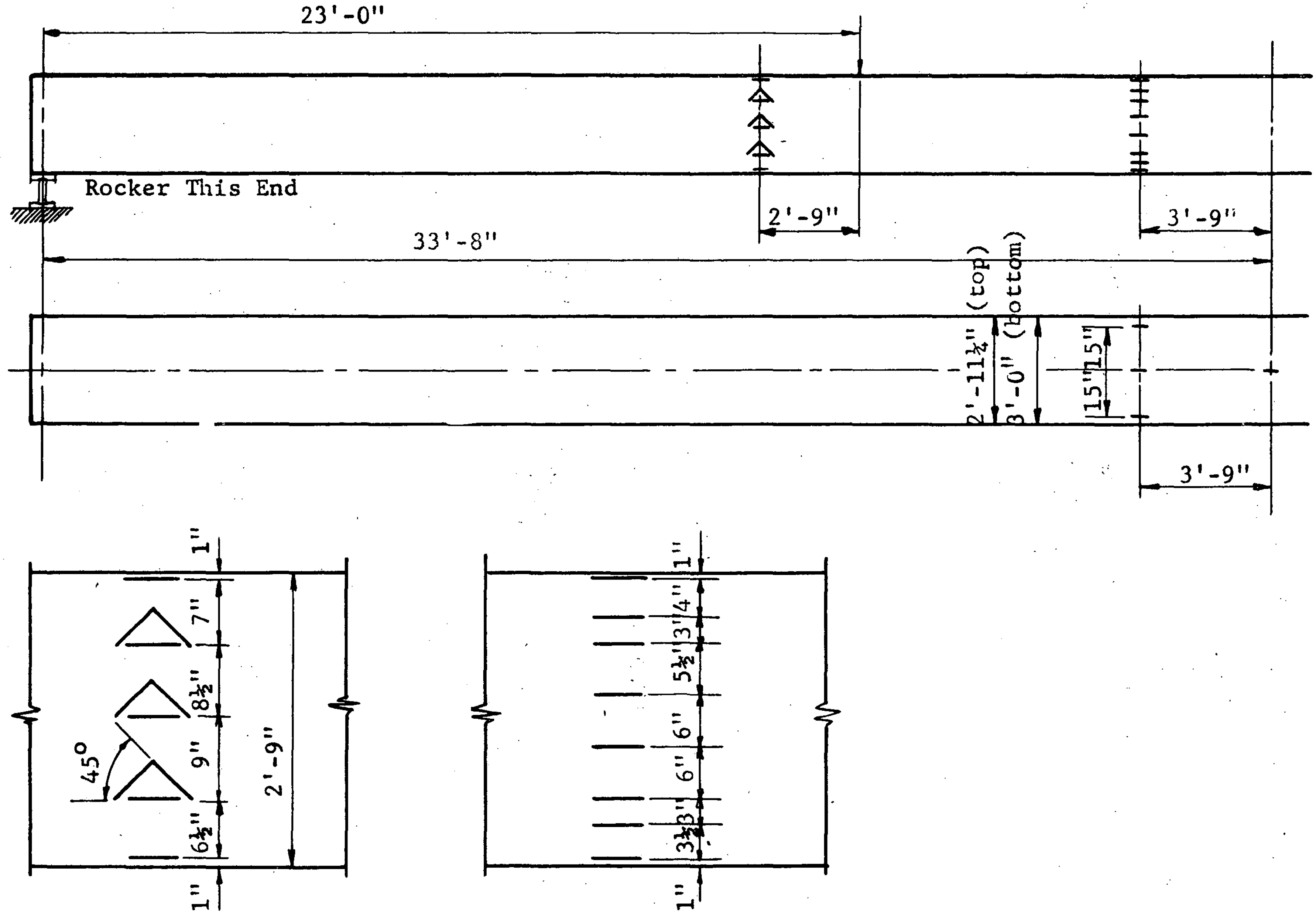


Fig. 11 - POSITION OF ELECTRICAL STRAIN GAGES

beam shortening, strand slip and deflections. During the manufacture of the beam the longitudinal pipe-rod device for measurement of beam shortening and lengthening had been inserted as was the Whittemore plugs and the strand dynamometer. Fig. 12 shows the overall picture of the testing setup with the hydraulic jacks symmetrically placed at 21 ft 4 in. centers.

The testing was commenced on February 23, 1956.

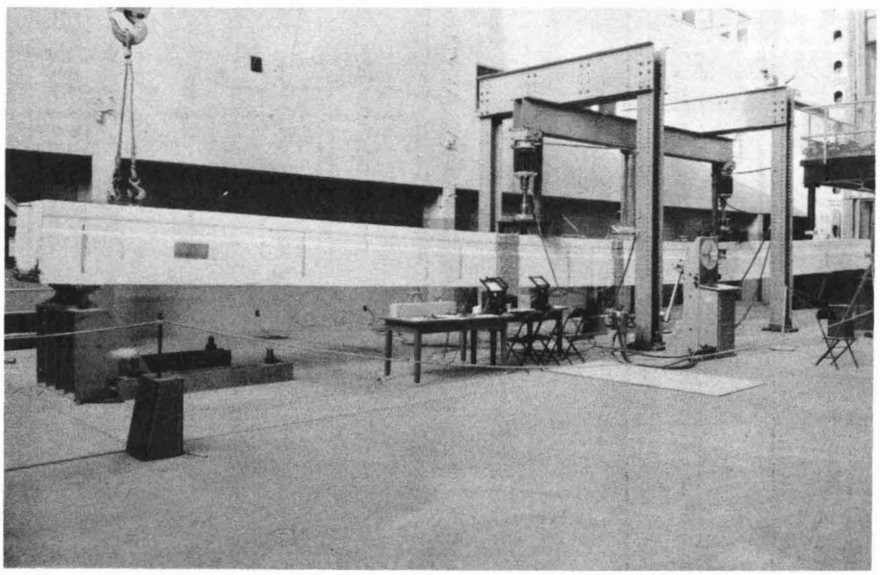


Fig. 12 - Overall Picture of Testing Setup

The beam was subjected to loadings in three groups, as follows:

I. 0 to design load (16,150 lbs)

II. Design load to cracking load (35,500 lbs)

III. Cracking load to ultimate load (74,000 lbs)

Group I was performed on the first day of testing culminating with a sustained design load being applied to the beam for a period of eight hours. Upon removal of the load the beam was allowed to recover for eight hours.

Group II consisted of a series of loadings that were increased until the first crack was observed in the beam. Here a sustained cracking load was applied to the beam for a period of forty-eight hours. Upon removal of the load the beam was allowed to recover for four hours.

Group III consisted of a series of increasing loads until ultimate load was reached.

In all three groups pertinent data was obtained and recorded.

The Determination of Design Load

Design load was determined from criteria of the AASHO and the Pennsylvania Department of Highways. A standard

H20 S16-44 load was used with 60 per cent of a wheel load carried by each beam. This loading resulted in a simulated design load of 16,150 lbs per jack being applied to the beam. (See Appendix B for calculations.)

The loading sequence is outlined in Table No. 3 and is shown graphically in Fig. 13.

Table 3 - Loading Sequence

Loading Sequence	Applied Load P (kips)	Points on Figs. 14, 15, 16	Points on Figs. 17,18, 19,20,&21	Remarks
I	0-4-0			
II	0-4-8-12-16-8-0	0-A-B	A-B-C	
III	0-16-0	0-C-D-E	A-B-B-C	Sustained 16.15^k load for 8 hrs.
IV	0	E	C	Beam recovered for 8 hrs.
V	0-16-20-24-28-32-35.5-0	E-F-G-H-I	D-E-F-G	Sustained 35.5^k load for 2 hrs.
VI	0-35.5	I-J-K	G-H-J	Sustained 35.5^k load for 48 hrs.
VII	35.5-0	K-L	J-K	
VIII	0	L-M	K-L	Beam recovered for 4 hrs.
IX	0-40-ultimate	M-N-ult.	L-M-ult.	

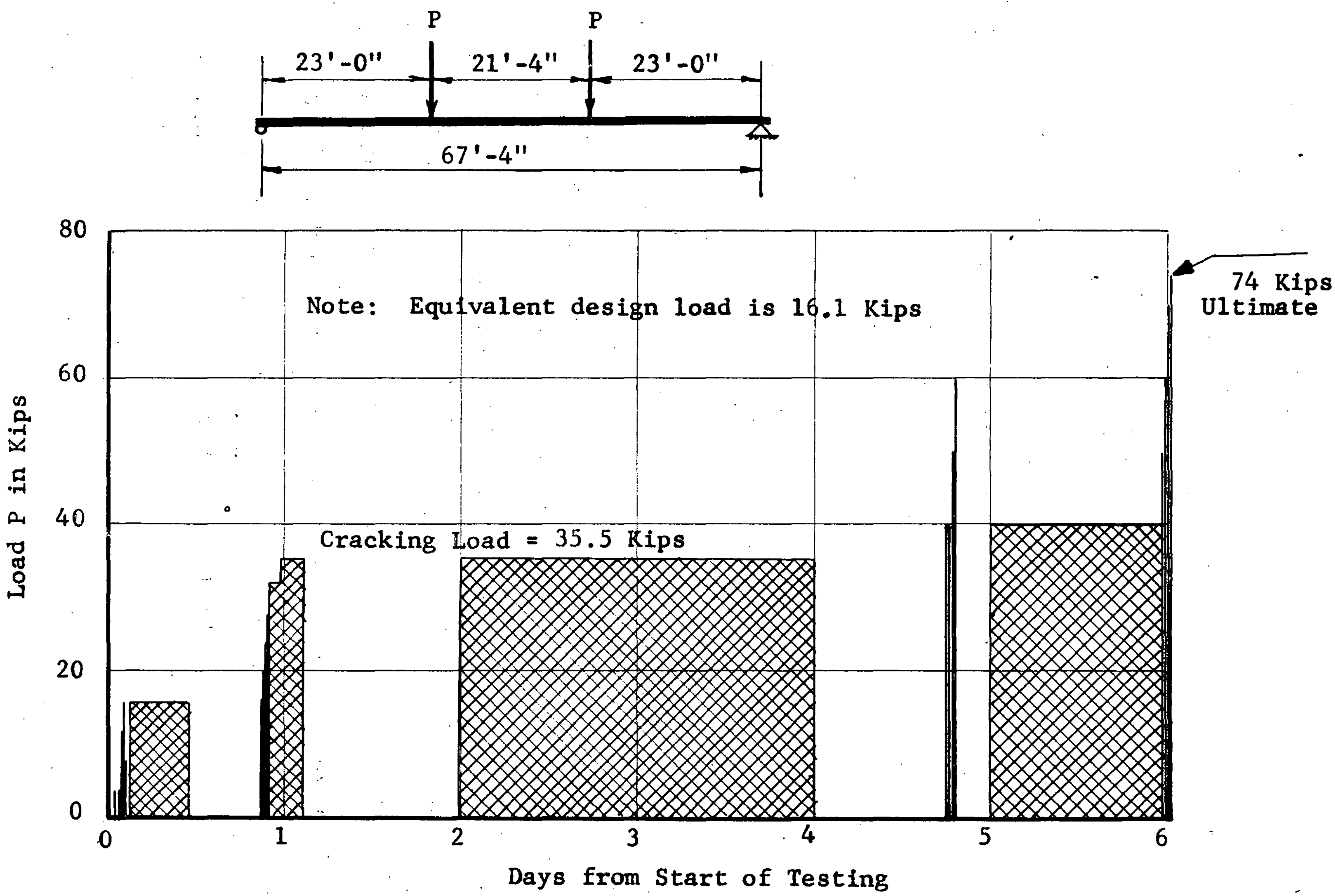


FIG. 13 - LOADING SEQUENCE FOR STATIC TEST

Deflections

Figures 14 through 16 depict the load-deflection characteristics of the beam as measured at the center of span.

Initial loadings subjected the beam to those loads up to and including the design load of 16,150 lbs per jack. This is shown in Figure 14 as run 0-A-B (an enlarged graph is shown in Figure 15). The observed deflection of 0.76 in. is well below the predicted deflection of 0.83 in.

Figure 16 (curve CD) shows the relationship of time and deflection at a sustained design load of 16,150 lbs per jack. Note that over the short period of time considered, a linear relationship occurred. Over a period of eight hours the deflection increased approximately nine per cent; however, upon release of load (D to E, Fig. 14) and then subsequent loading to 20,000 lbs per jack (E to F, Fig. 14) the plot returned to an extension of the course of the initial loading shown by the line A-F.

Cracking load of 35,500 lbs per jack induced a deflection of 2.07 inches, point G in Fig. 14. Cracking load was held for two hours (GH) and then upon release of this load (HI) a deflection of 0.331 inches occurred at the center of span.

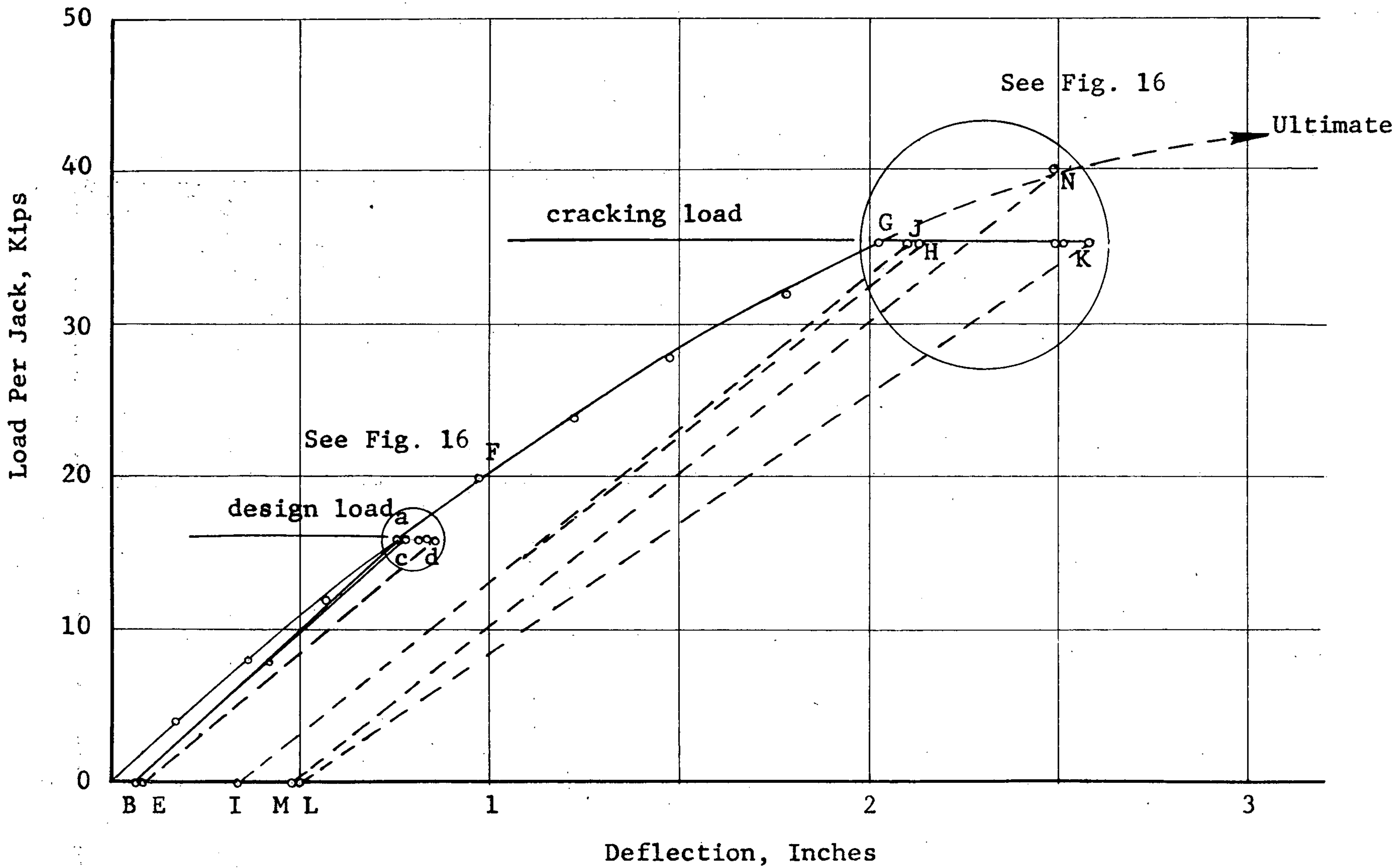


Fig. 14 - DEFLECTIONS DUE TO APPLIED LOAD

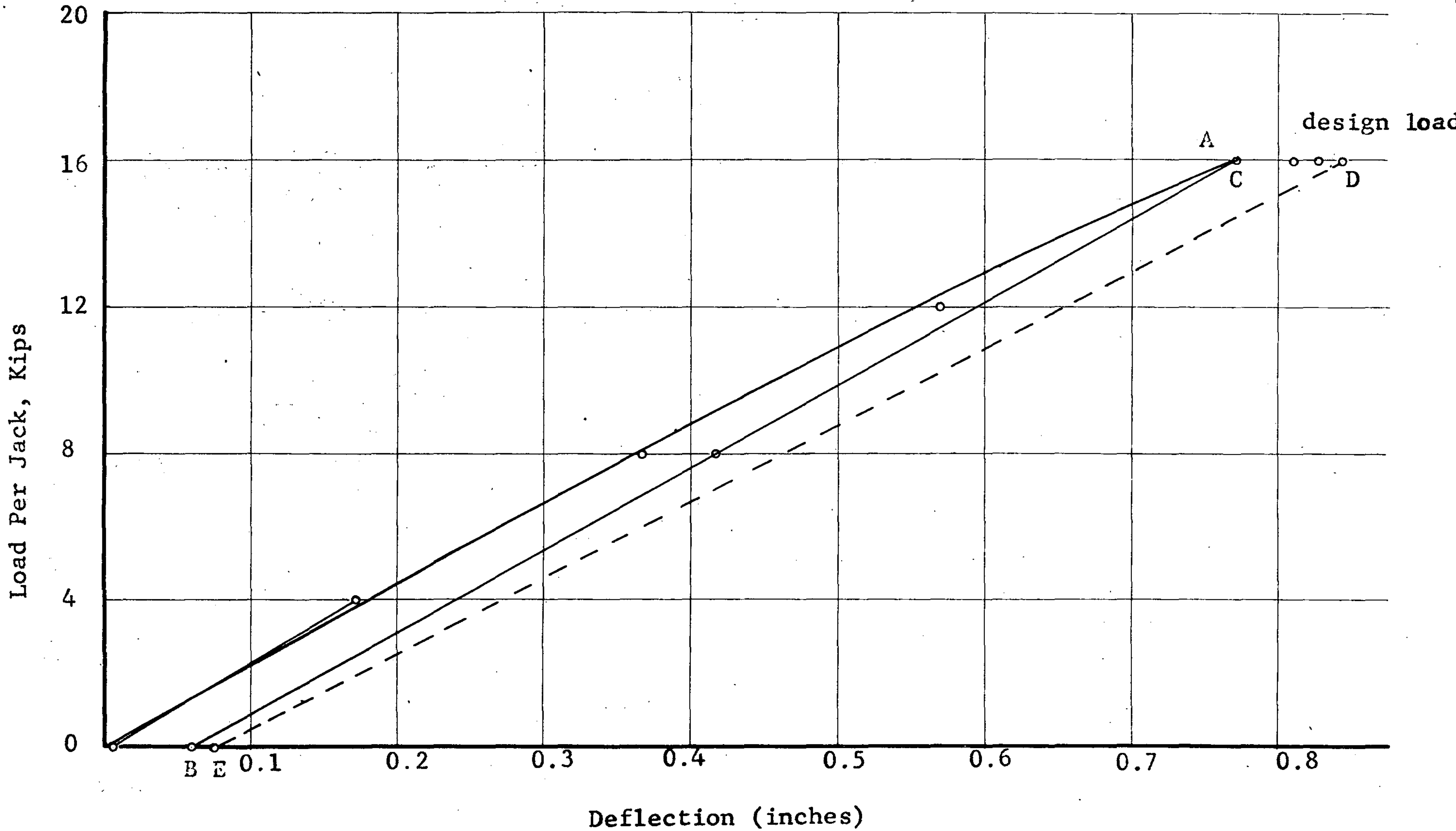


Fig. 15 DEFLECTIONS WITHIN DESIGN LOAD

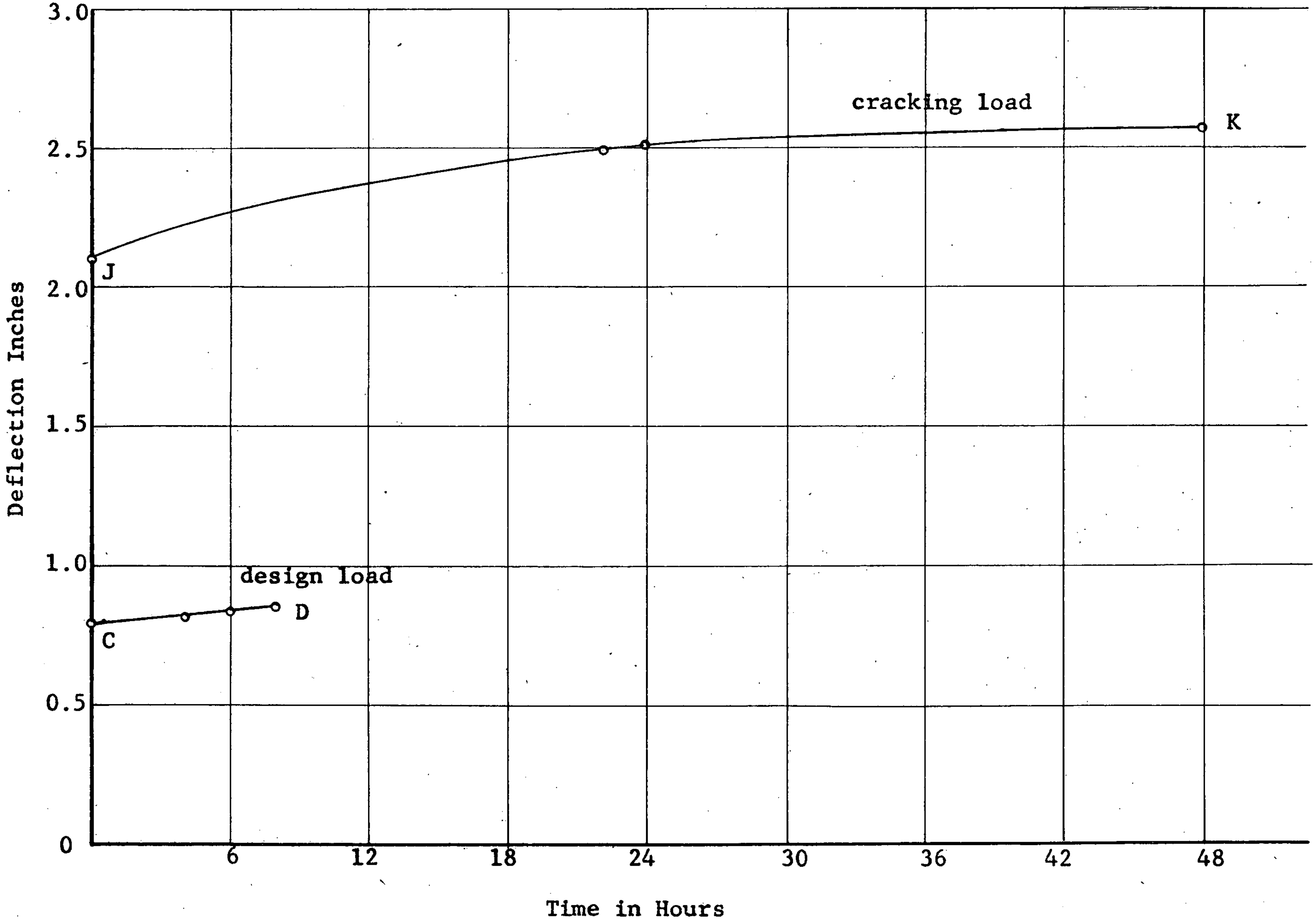


Fig. 16 - DEFLECTION VS TIME AT SUSTAINED LOADINGS

Figure 16 shows that under sustained cracking load the beam increased in deflection by 23 per cent (JK) over a period of 48 hours. The deflection in this case did not show a linear relationship with time, however, as the deflections seemed to approach a limit as the time increased. This is illustrated by the rapid reduction of the slope and the assymptotic appearance of the curve in Fig. 16.

Returning again to Fig. 14, we see that after the release of the sustained cracking load (KL), and subsequent loading to 40 kips per jack, the plot returned to the projected course (GN) of the initial curve.

The load deflection curve was used to determine the modulus of elasticity of the concrete based upon the secant of the curve from the origin to the point corresponding to design load of 16,150 lbs per jack. E_c was found to be 5,050,000 psi.

<u>Load vs. Total Shortening</u>

Fig. 17 is a plot of the load applied by each jack, at the approximate third points of the beam, versus the total shortening of a longitudinal fiber 1-1/2 in. from the top surface of the beam. This total shortening is a

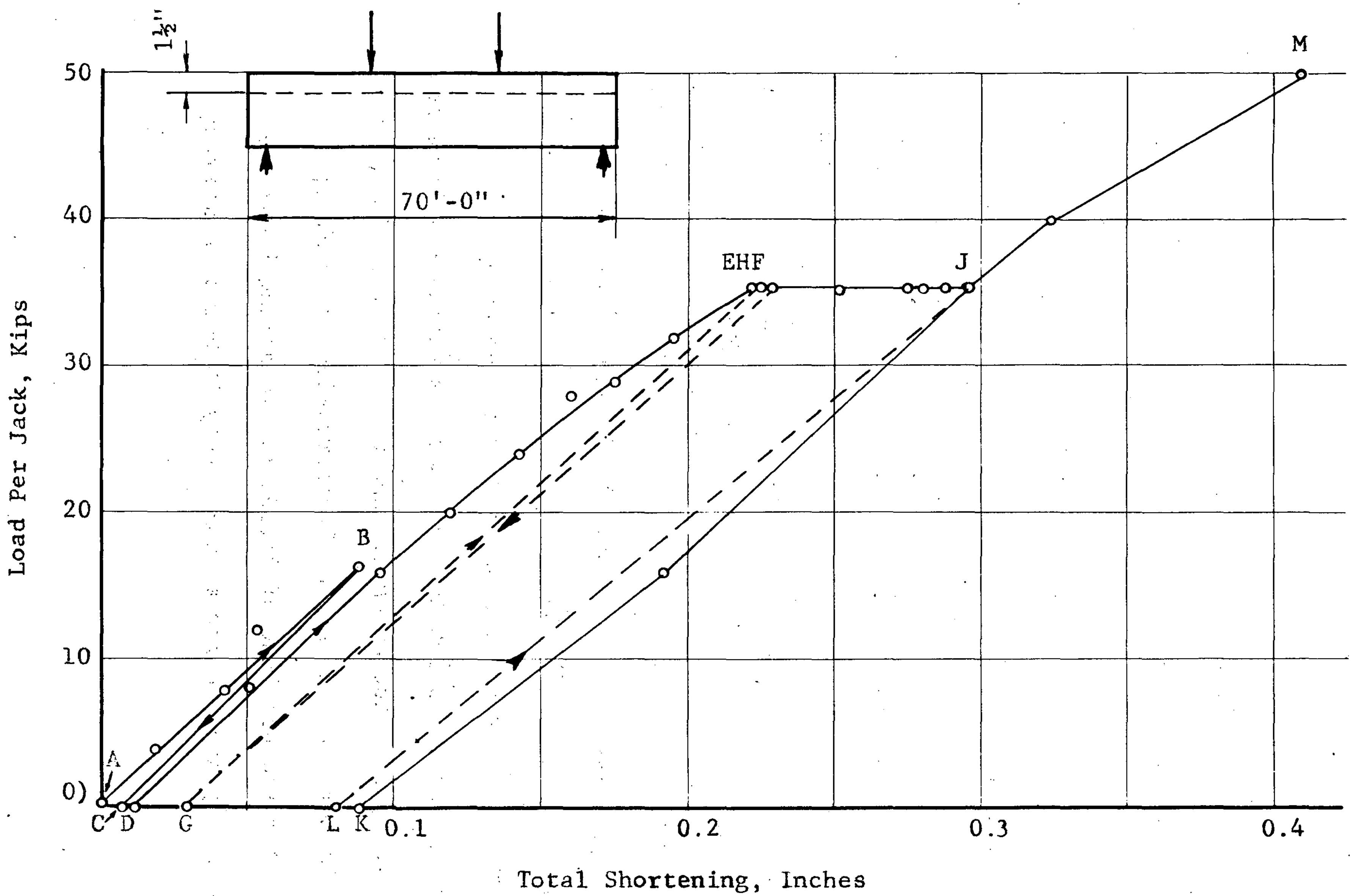


Fig. 17 - TOTAL SHORTENING UNDER APPLIED LOAD

summation of the fiber unit strains taken over the length of the beam. The features or characteristics of the curves plotted in Fig. 17 will be discussed at this point.

Curve ABC shows that the total shortening of this fiber was directly proportional to the loads applied at the jacks up to a design load of 16,150 lbs per jack. The design load held for eight hours and released gave a residual fiber deformation represented by segment AC of about nine per cent. The value of the modulus of elasticity of the concrete was found to be 5.1 x 10^6 psi, based upon the slope of curve AB. See Appendix C for the derivations and calculations.

Varying the load from zero to 35,500 lbs per jack and returning to zero load produced curve DEFG. This plot shows that the shortening of the fiber was almost directly proportional to the loads applied at the jacks up to the cracking load of 35,500 lbs and that the residual deformation after release of the cracking load was 0.026 in., (AG), or about 11 per cent of the total deformation at cracking.

A sustained load of 35,500 lbs (cracking load) was subsequently applied for approximately 48 hours as shown by

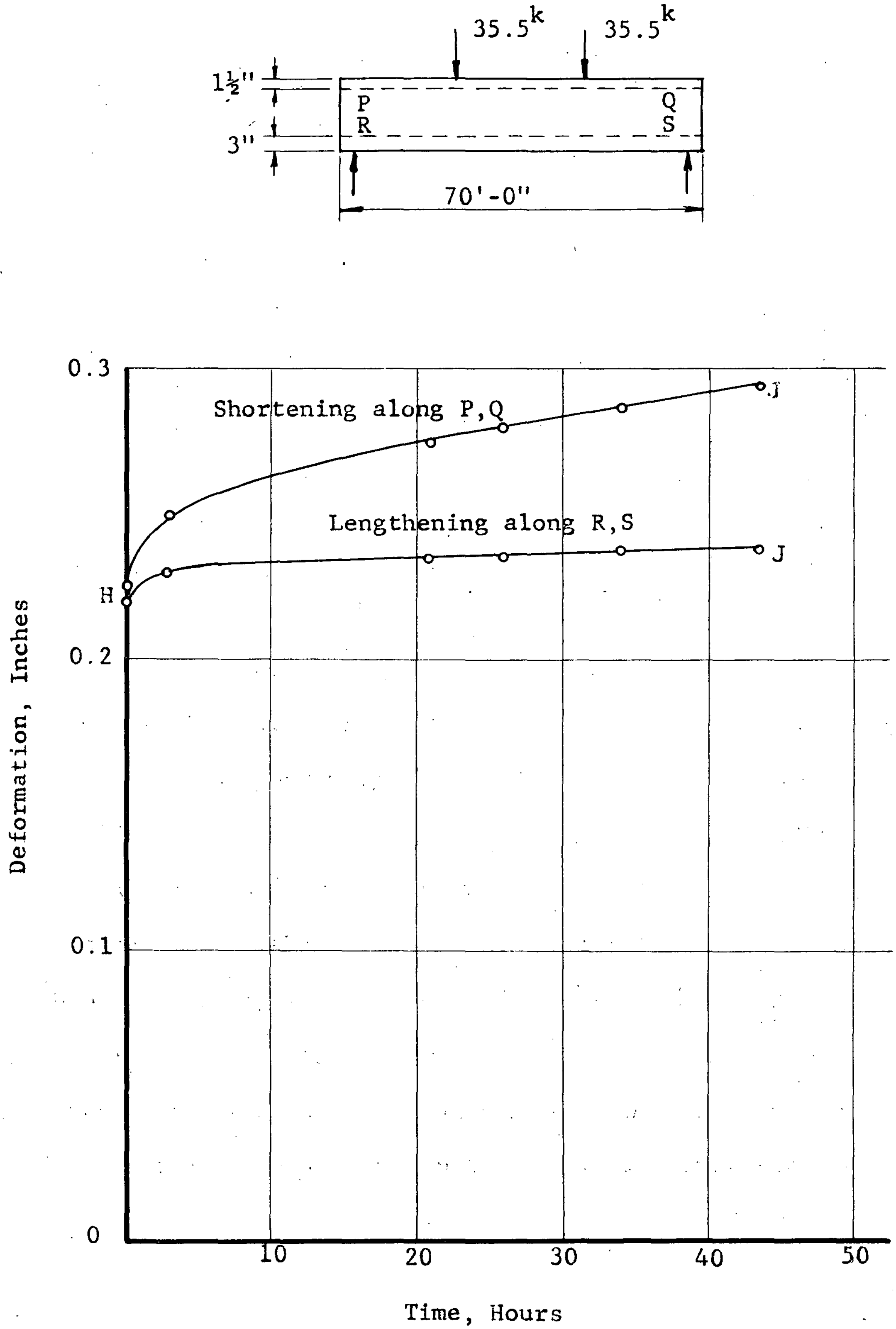


Fig. 18 - FIBER DEFORMATION UNDER SUSTAINED CRACKING LOAD

GHJK in Fig. 17. During this time the top fiber shortened by 30 per cent under this load of 2.2 times design load. The variation of the shortening along fiber PQ with time under the applied cracking load is shown in Fig. 18. Returning to Fig. 17, it can be seen from the distance AK that the residual deformation of the fiber after release of the cracking load was 0.087 in., or about 36 per cent of deformation at cracking load.

Load vs. Total Lengthening

Fig. 19 is a plot of the load applied by each jack, versus the total lengthening of a longitudinal fiber 3 in. from the bottom surface of the beam. This total lengthening is a summation of the fiber unit strains taken over the length of the beam.

Curve ABC shows that the total lengthening of this fiber was directly proportional to the loads applied at the jacks up to a design load of 16,150 lbs per jack. The load was held for eight hours and after release the residual fiber deformation AC, was only 0.006 in. or eight per cent of the deformation at design load. The value of the

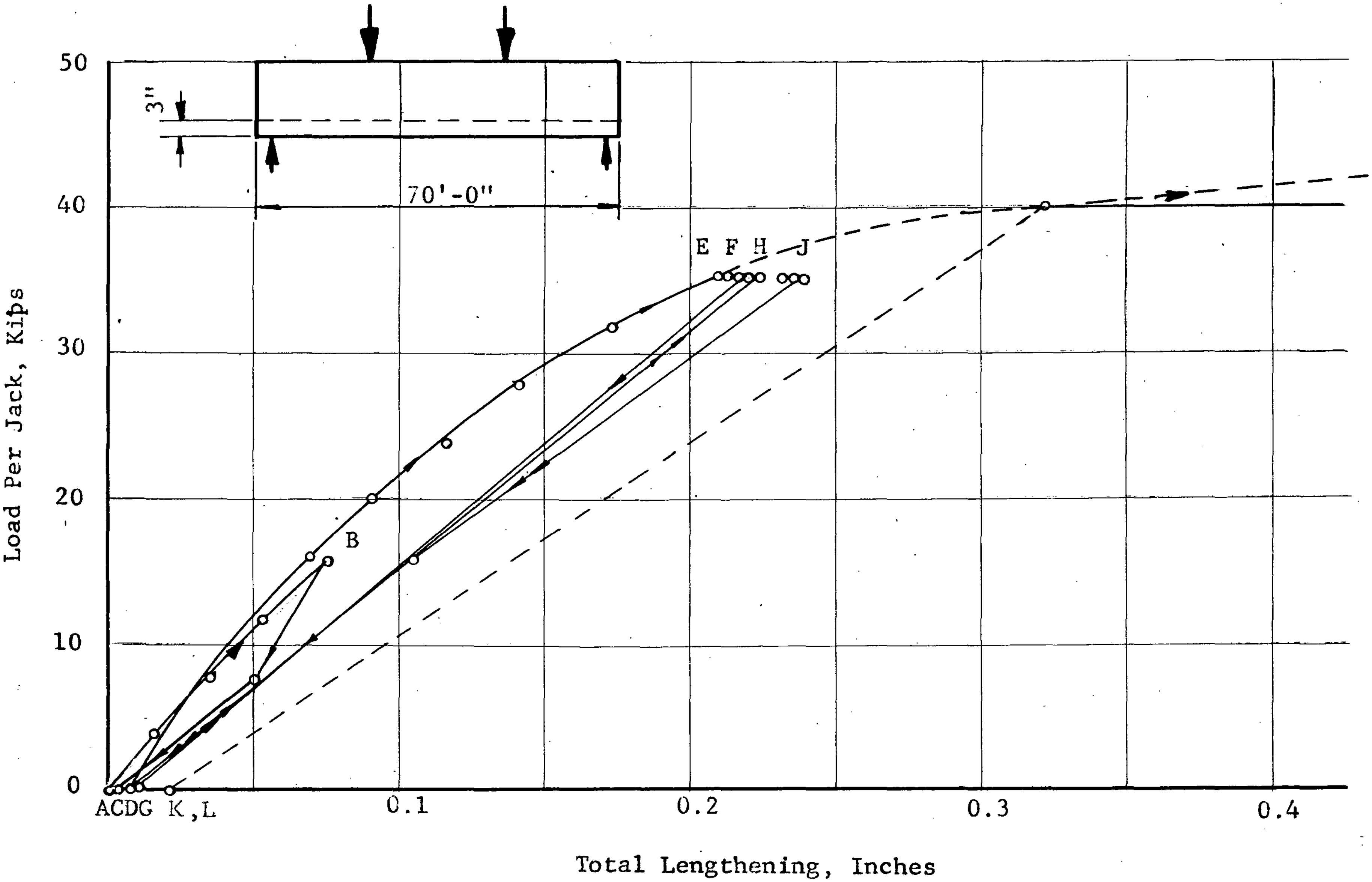


Fig. 19 - TOTAL LENGTHENING UNDER APPLIED LOAD

molulus of elasticity was found to be 5.3 x 10^6 psi, based upon the slope of the secant of curve AB. See Appendix C for the calculations.

It is shown in Fig. 19 that the bottom curve DEF to 35,500 lbs has about the same shape as corresponding curve EFG for deflections in Fig. 14. After release of the load, which was held for two hours, the residual deformation, AG, was 0.010 in., or about five per cent of the deformation at cracking load.

Under the 48-hour sustained cracking load of 35,500 lbs per jack, GHJK, the bottom fiber lengthened 0.014 in., or only about six per cent. See also curve HJ in Fig. 18. The residual deformation, AD, of this fiber after release of the cracking load was only 0.007 inches.

The bottom fibers, hence the load-total lengthening curve, are more seriously affected by the load above cracking than are the top fibers as can be seen by comparing the post cracking curves of Figs. 17 and 19. The segment JM in Fig. 17 indicates considerable stiffness, whereas the corresponding segment in Fig. 19 indicates a rapid formation of cracks.

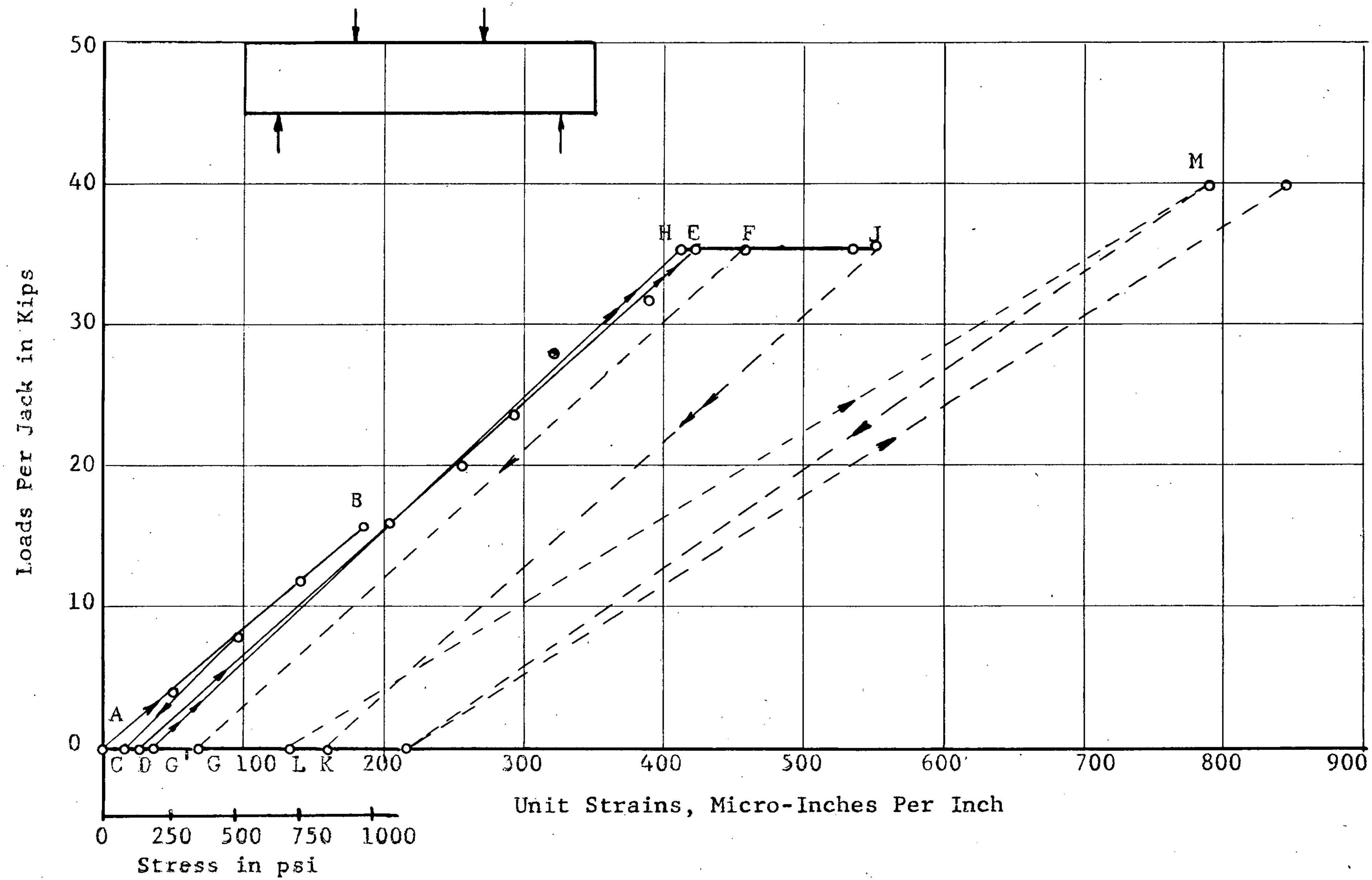


Fig. 20 - STRAIN OF BOTTOM FIBER AT MIDSPAN - BEAM UNDER APPLIED LOAD

Applied Load Unit Strains of the Top and Bottom Fibers in the Region of Maximum Moment.

Fig. 20 shows the variation of the tensile fiber unit strain in the region of maximum moment versus the load applied approximately at each third point of the beam. Fig. 21 is a similar curve for a compressive fiber in the region of maximum moment. Unit stresses are shown beneath the unit strain scales on these figures up to design load. These stresses are based on a modulus of elasticity value obtained from deflection and beam fiber total deformation experimental results. The data plotted in Figs. 20 and 21 was obtained from SR4-A9 electrical strain gages placed on the bottom and top surfaces of the beam between the load points as shown in Fig. 11.

Curve OAB of both Figs. 20 and 21 show that the tensile and compressive unit strains (and unit stresses) are both directly proportional to the load applied at the jacks. Curve EFG of Fig. 20 and curve EFG of Fig. 21 show that this direct proportion between applied load and the fiber unit strains holds for all practical purposes up to the cracking load.

Curve JK of Fig. 20 and curve JK of Fig. 21 show the increase in unit strain of the bottom and top fibers under a

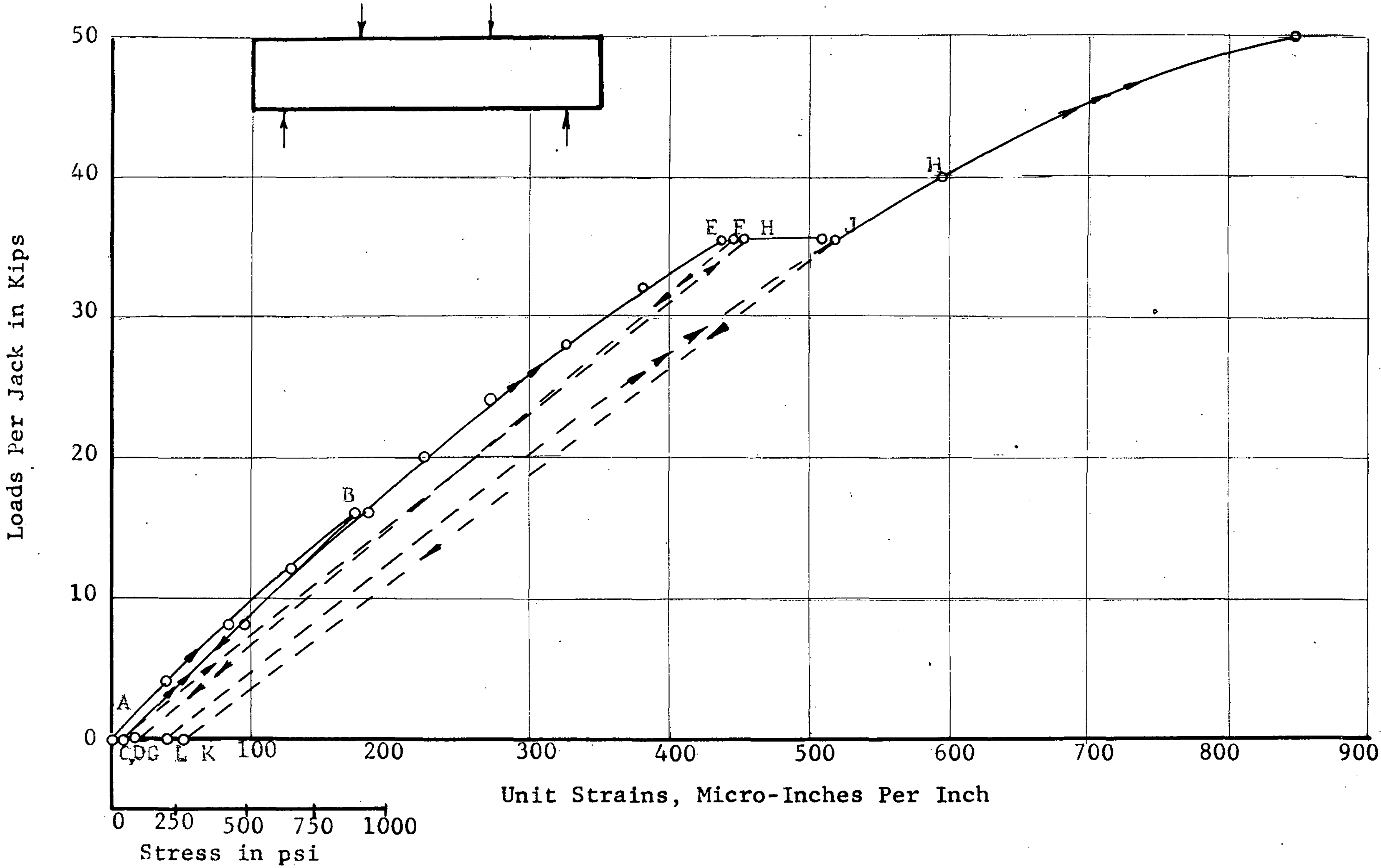


Fig. 21 - STRAIN OF TOP FIBER AT MIDSPAN - BEAM UNDER APPLIED LOAD

sustained cracking load of 35.5 kps. The bottom fiber unit strain increased about 140 micro inches per inch and the top fiber unit strain increased about one half of this amount or 70 micro inches per inch.

The residual deformation of the top fiber was never more than 50 micro inches per inch even after the sustained cracking load had been applied. The maximum residual deformation of the bottom fiber was about 150 micro inches per inch after the sustained cracking load had been applied. Residual deformation before cracking is negligible.

Whittemore Strain Readings

Referring to Fig. 7 it can be seen that the applied load had no effect on the anchorage length at the end of the beam. The anchorage length of the strand remained the same regardless of the load; this is shown by the average curve AB plotted.

Fig. 7 also shows the effect of the applied loads upon the top fiber, measurements taken at five different points along the beam.

Ulimate Moment

The calculated ultimate moment was found to be 24,525,000 in. lbs (see design calculations in the appendix).

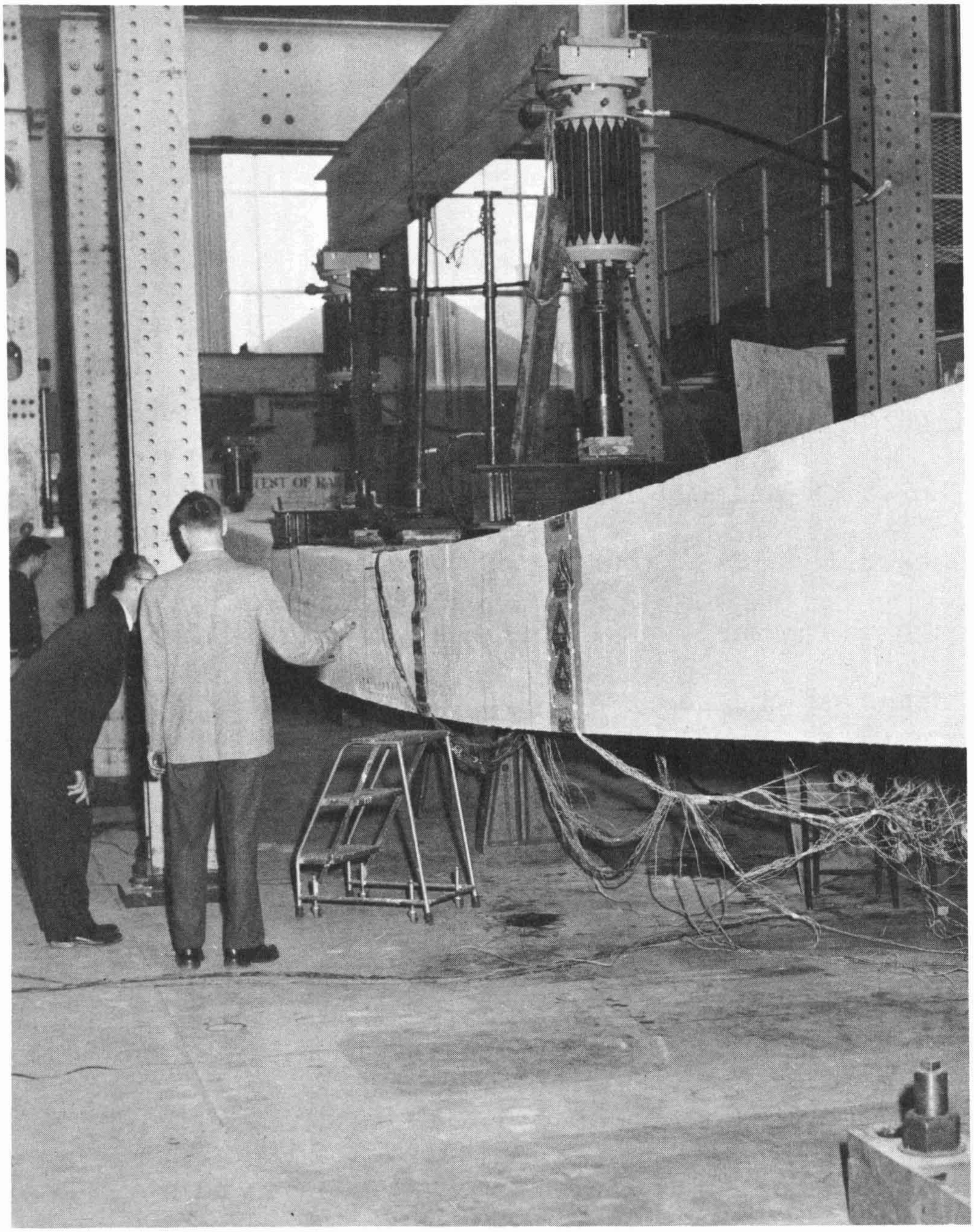


Fig. 22 - Beam Near Ultimate Load

Observed ultimate moment was found to be 24,742,000 in. lbs; and the deflection of the beam at midspan was in excess of 30 in. just before the ultimate load was reached.

Crack Pattern

The initial flexural crack occurred at a jack loading of 35,500 lbs giving a total maximum moment of 14,118,000 in. lbs or 1.46 (D+L+I)*.

The crack pattern is shown in Fig. 22. The views indicate excellent distribution of relatively small cracks even though the moment was 19,518,000 in. lbs or 2.02 (D+L+I)* at this stage of the test. It is interesting to note that the most severe cracking occurred in the half of the beam that was closest to the fixed support rather than in the half nearest the expansion support.

From a corrosion standpoint a crack width must exceed 0.010 in. to be considered harmful. It is of interest to note that a maximum crack width of 0.010 in. was not attained until a maximum moment of approximately 16,910,000 in. lbs or 1.75 (D+L+I)*, was reached.

Fig. 23 shows a view of the expansion support and another view of the fixed support. Considerable difficulty was

* The term (D+L+I) is given here for a 70 foot span. See Appendix B.

experienced at the expansion end at high loads due to the fact that the bottom fiber elongated to cause the rocker to tip over. When the rocker tipped over, the load was maintained at the third points while the end was jacked up to allow for resetting the rocker.

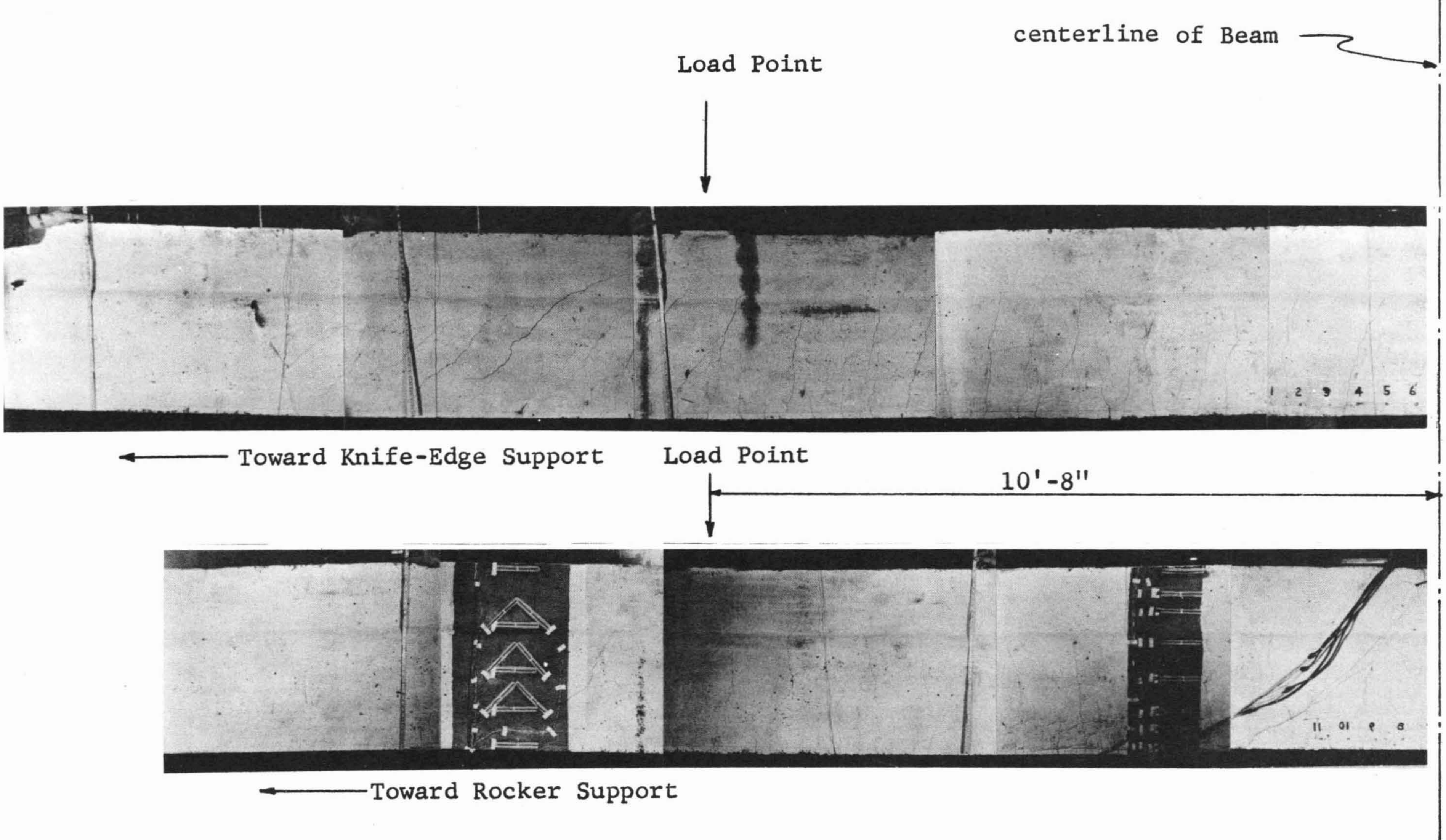
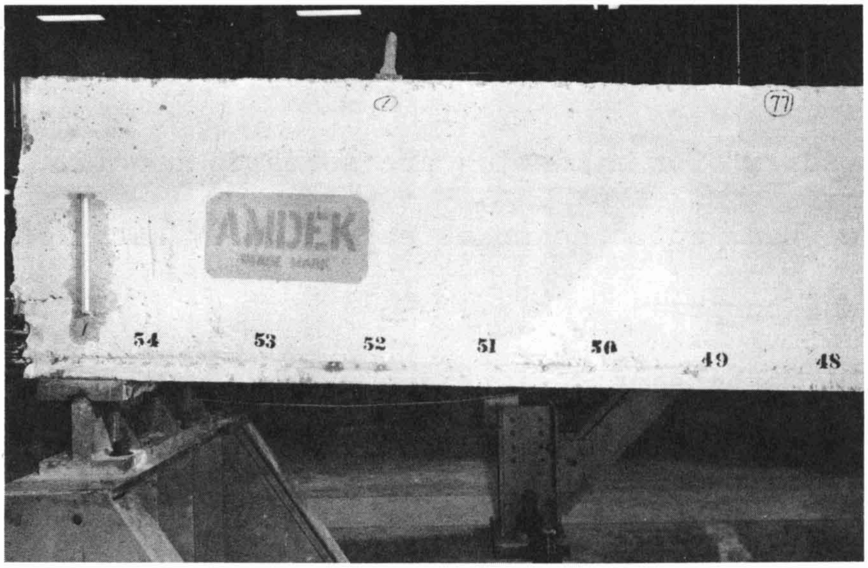
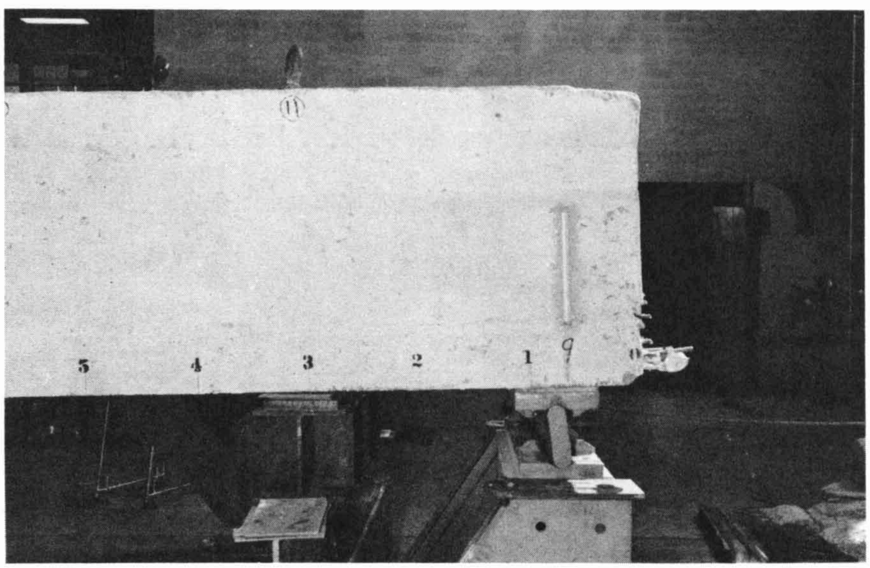


Fig. 23 - CRACK PATTERN WITH 55,000 LBS AT EACH LOAD POINT



Fixed End



Expansion End

Fig. 24 - Views Showing End Supports

CONCLUSIONS
70 FT. BEAM REPORT

The results of the testing are summarized below.

1. The beam appeared to be structurally satisfactory for its intended purpose.

2. The methods of design appear to be satisfactorily accurate.

3. The cracking moment was observed to be

$$1.46(D+L+I)$$

where the value of (D+L+I) represents the total design moment for a span measuring 70 ft. center to center of supports. (See Appendix B).

4. A maximum measured crack width of 0.010 in. was reached at a total moment of

$$1.75(D+L+I)$$

where the term (D+L+I) has the same meaning as above.

5. The deflection under design loading did not exceed 0.80 in. = $L/_{1000}$. The deflection under cracking load was 2.07 in. = $L/_{270}$, and under sustained cracking load for 48 hours the maximum deflection was 2.60 in. = $L/_{216}$. The deflection at ultimate load was over 30 in..

6. No end slip of the strand occurred at any stage of the test.

7. Failure of the beam was due to crushing of the concrete without substantial elongation of the steel.

8. The ultimate moment was observed to be

$$2.55(D+L+I)$$

where the term (D+L+I) has the same meaning as above. This value is almost identical with the computed ultimate moment.

9. The concrete had a compressive strength of 5650 psi at the time of laboratory testing on the basis of tests on core samples taken from the beam. The modulus of elasticity of the concrete was slightly in excess of 5,000,000 psi at the time of testing.

ACKNOWLEDGEMENTS

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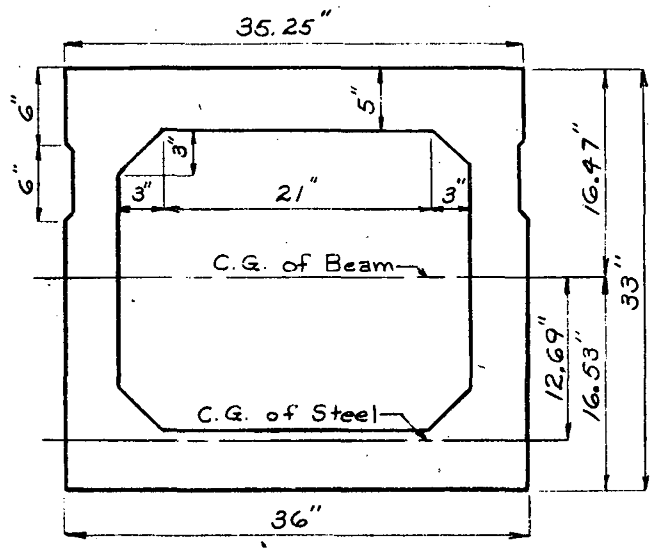
Rene Walther was in charge of organizing and conducting the tests. He was assisted by Louis J. Debly, George F. Heimberger, Charles E. Stuhlman, Cengiz Gokkent. John W. McNabb and George A. Dinsmore also provided valuable help during the carrying out of the test program.

The initial phases of the writing of this report was done with the assistance of George F. Heimberger.

APPENDIX A - ANALYSIS OF BEAM

Section Properties



Center of Gravity of Concrete to Top Fiber, y_t = 16.47 in.

Center of Gravity of Concrete to Bottom Fiber, y_b = 16.53 in.

C. G. of Concrete to C. G. of Steel, e = 12.69 in.

Moment of Inertia of the Section, $I_c = 78900 \text{ in.}^4$

Section Modulus (top fiber), $S_t = \frac{78900}{16.47} = 4790 \text{ in.}^3$

Section Modulus (bottom fiber), $S_b = \frac{78900}{16.53} = 4770 \text{ in.}^3$

Moments

Dead Load

weight of beam $= 558 \times \frac{150}{144} = 580$ lb/ft

wt. of bulkhead $= 889.5 \times \frac{150}{144} = 1853$ lb

wearing surface = 90 lb/ft

$$M_b = \frac{580(67.33)^2(12)}{8} + \frac{1853(67.33)(12)}{4} = 4{,}318{,}000 \text{ in-lb}$$

$$M_s = \frac{90(67.33)^2(12)}{8} = 612{,}000 \text{ in-lb}$$

Live Load

Fraction of wheel load per beam = $\frac{S}{5} = \frac{3}{5}$

or $\frac{3}{10}$ of a lane load

From A.A.S.H.O. - $M_{LL} = \frac{3}{10}(937.2)(12) = 3374$ in-kips

$= 3{,}374{,}000$ in-lb

Shear

Dead Load

$V_b = \frac{1}{2}(580)(67.33) + \frac{1}{2}(1853) = 20{,}440$ lb

$V_s = \frac{1}{2}(90)(67.33) = 3030$ lb

Live Load

$V_{LL} = \frac{3}{10}(62000) = 18600$ lb

Summation

	Shear(lb)	Moment(in-lb)
Live Load	18,600	3,374,000
Impact (26%)	4,840	877,000
Beam	20,430	4,318,000
Wear. Surface	3,030	612,000
Total	46,900	9,181,000

Prestressing

Area of Steel = 46(0.08) = 3.68 sq. in.

Initial Pretensioning Force, $P_i = 3.68(150{,}000) = 552{,}000$ lb

Final Pretensioning Force(assuming 20% loss), $P_f = 0.80(552{,}000)$

$= 441{,}600$ lb

. Stresses

Prestressing

Initial Top Fiber, $f_c = -\frac{P}{A} + \frac{Pe}{S}$

$$= -\frac{552,000}{558} + \frac{12.69(552,000)}{4790}$$

$$= +\ 473 \text{ psi}$$

Final Top Fiber, $f_c = -\frac{441,600}{558} + \frac{12.69(441,600)}{4790}$

$$= +\ 379 \text{ psi}$$

Initial Bottom Fiber, $f_c = -\frac{552,000}{558} - \frac{12.69(552,000)}{4770}$

$$= -\ 2458 \text{ psi}$$

Final Bottom Fiber, $f_c = -\frac{441,600}{558} - \frac{12.69(441,600)}{4770}$

$$= -\ 1966 \text{ psi}$$

Live Load plus Impact

Top Fiber, $f_c = \frac{M}{S} = \frac{3,374,000 + 877,000}{4790} = -\ 887$ psi

Bottom Fiber, $f_c = \frac{4,251,000}{4770} = +\ 891$ psi

Dead Load

Wt. Beam: Top Fiber, $f_c = \frac{4,318,000}{4790} = -\ 901$ psi

Bottom Fiber, $f_c = \frac{4,318,000}{4770} = +\ 905$ psi

Surfacing: Top Fiber, $f_c = \frac{612,000}{4790} = -\ 128$ psi

Bottom Fiber, $f_c = \frac{612,000}{4770} = +\ 128$ psi

Summary of Stresses (at center of beam)

	1	2	3	4	5	6	7	8
	P initial	P final	D.L. beam	D.L. w.s.	L.L.+ Imp.	1+3	2+3	4+5+7
Top	+ 473	+ 379	-901	-128	-887	- 428	- 522	-1537
Bottom	-2458	-1966	+905	+128	+891	-1553	-1061	- 42

Ultimate Strength of Section

Plastic Ratio

$$\beta = \frac{1}{1+(f'_c/4000)^2} = 0.334$$

Steel Ratio

$$p = \frac{A_s}{bd} = \frac{3.68}{35.25(29.16)} = 0.00358$$

Neutral Axis Ratio

$$K = \frac{2pf'_s}{(1+\beta)f'_c} = \frac{2(0.00358)(250,000)}{(1+0.334)(5650)} = 0.237$$

Moment Arm Ratio

$$j = 1 - \left[\frac{1+\beta+\beta^2}{3(1+\beta)}\right] K = 1 - (0.362)(0.237) = 0.914$$

Ultimate Moment

$$M = A_s f_s jd = 3.68(250,000)(0.914)(29.16)$$

$$= 24,525,000 \text{ in-lb}$$

Safety Factor

$$S.F. = \frac{24,525,000}{9,181,000} = 2.67$$

Experimental Ultimate Moment

$$M_{ex.} = 74,000(23)(12) + 4,318,000 = 24,742,000 \text{ in-lb}$$

Comparison Between Actual and Theoretical

$M_{ex.}$ = 24,742,000

$M_{th.}$ = 24,525,000

217,000 = Difference

Percent Difference = 0.885%

Principal Tensile Stresses

At Centroid (over support)

$$Q = \left[\frac{(16.53)^2(36)}{2}\right] - \left[\frac{(12.03)^2(27)}{2}\right] + \left[2(3)(3)\tfrac{1}{2}(11.03)\right]$$

$$= 3063 \text{ in.}^3$$

$$S_x = \frac{P}{A} = -989 \text{ psi}$$

$$v = \frac{VQ}{Ib} = \frac{46,900(3063)}{78,900(9)} = 202 \text{ psi}$$

$$S_t = \sqrt{v^2 + (S_x/2)^2} - \frac{S_x}{2}$$

$$= \frac{1}{2}\left[\sqrt{4(202)^2 + (989)^2} - 989\right]$$

$$= + 40 \text{ psi}$$

At 8" From Top (over support)

$$Q = 8(36)(12.47) - \frac{3}{4}(6)(13.47) - 27(3)(9.97) + 3(3)(10.47)$$

$$= 2788 \text{ in.}^3$$

$$v = \frac{46,900(2788)}{78,900(7.5)} = 221 \text{ psi}$$

$$S_x = - 989 + \frac{12.69(441,600)(8.47)}{78,900} = - 387 \text{ psi}$$

$$S_t = \frac{1}{2}(- \sqrt{4(221)^2 + (387)^2} + 387)$$

$$= - 100 \text{ psi} < - 240 \text{ psi}$$

($\therefore$ Minimum stirrups were required)

At 8" From Top (over support at 2.5 x ultimate load)

$$v = 2.5(221) = 553 \text{ psi}$$

$$S_t = \frac{1}{2}(- \sqrt{4(553)^2 + (387)^2} + 387)$$

$$= - 393 \text{ psi} < - 480 \text{ psi}$$

($\therefore$ Minimum stirrups were required)

APPENDIX B - EQUIVALENT DESIGN LOAD

Introduction

The design was originally intended to be for a 70 ft. center-to-center span, but because of limited space in the laboratory, this span length could not be tested. It was decided, however, to base the design load on the 70 ft. distance rather than the actual distance of 67 ft. 4 in. The calculations are given below.

Summary of Moments
(70 ft. span)

Live (H20-S16-44)	3550 Kip-In.
Impact	902
Beam	4540
Surface	662
Total (D+L+I)	9654 Kip-In.

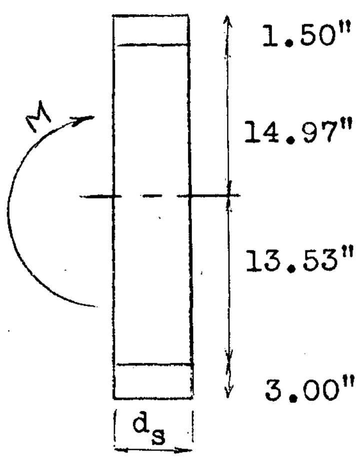
Equivalent Beam Loading

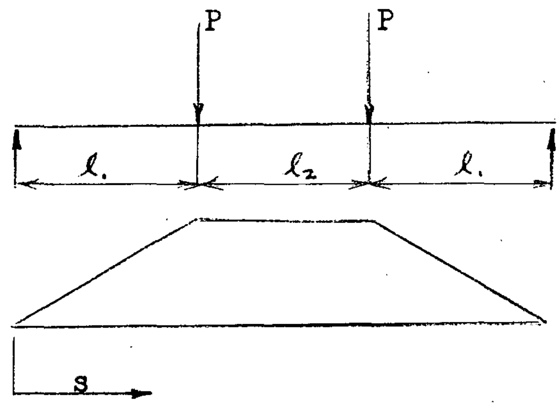
<u>Due to live load plus impact</u>

$$P = \frac{4452}{23x12} = 16.15 \text{ kips per jack.}$$

APPENDIX C - E_c VALUES FROM LENGTH CHANGES

Derivations





$$\int \epsilon \, d_s = \int \frac{My}{EI} \, d_s$$

$$\Delta = 2 \frac{y}{EI} \int_0^{\ell_1} M_1 d_s + y \frac{M_2}{EI} \int_0^{\ell_2} d_s$$

$$\Delta = \frac{y}{EI} \left[2 \int_0^{\ell_1} Ps d_s + P\ell_1 \int_0^{\ell_2} d_s \right]$$

$$\Delta = \frac{yP}{EI} \left[2 \frac{s^2}{2} \Big|_0^{\ell_1} + \ell_1 s \Big|_0^{\ell_2} \right] = \frac{yP}{EI} \left[\ell_1^2 - \ell_1 \ell_2 \right]$$

$$E = \frac{yP}{\Delta I} \left[\ell_1^2 - \ell_1 \ell_2 \right]$$

Calculations

$$E = \frac{yP}{\Delta} \left[276 \frac{(276 + 256)}{78900} \right] = 1.86 \frac{yP}{\Delta}$$

<u>Top Fiber</u>

$$E = 1.86 \frac{14.97(16.3)}{0.088} = 5.16 \times 10^6 \text{ psi}$$

<u>Bottom Fiber</u>

$$E = 1.86 \frac{13.53(15.8)}{0.076} = 5.23 \times 10^6 \text{ psi}$$