ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN

Technical Report

TESTS OF FLEXICORE SLABS MADE OF ELASTIZELL CONCRETE

Alex E. Mansour
Engineer, Elastizell Corporation of America

and

L. M. Legatski,
Professor of Civil Engineering
University of Michigan

Project 2326
ELASTIZELL CORPORATION OF AMERICA
ALPENA, MICHIGAN

November, 1957

TABLE OF CONTENTS

TESTS OF FLEXICORE SLABS
MADE OF
ELASTIZELL CONCRETE

INTRODUCTION

"Flexicore" is the trade name applied to a type of hollow precast concrete slab used for floor and roof construction. In structural action the Flexicore member is essentially a T beam. The concrete stress almost never controls in T beams. Therefore, if a concrete having other desirable properties, such as light weight and lower thermal conductivity, is to be used in Flexicore it need not be high strength concrete. It must be strong enough to resist the calculated T beam stresses and stiff enough to satisfy deflection requirements.

Elastizell concrete is a cellular concrete which can be made in a wide range of densities by replacing a varying amount of fine aggregate by tiny air cells, thus reducing the weight of the mix. As the weight of the material is decreased by the addition of air the compressive strength and the thermal conductivity are also decreased. A mix having adequate strength for Flexicore members can be made at a weight saving of about 25% and with a 45% decrease in thermal conductivity without the necessity of storing and using lightweight aggregates.

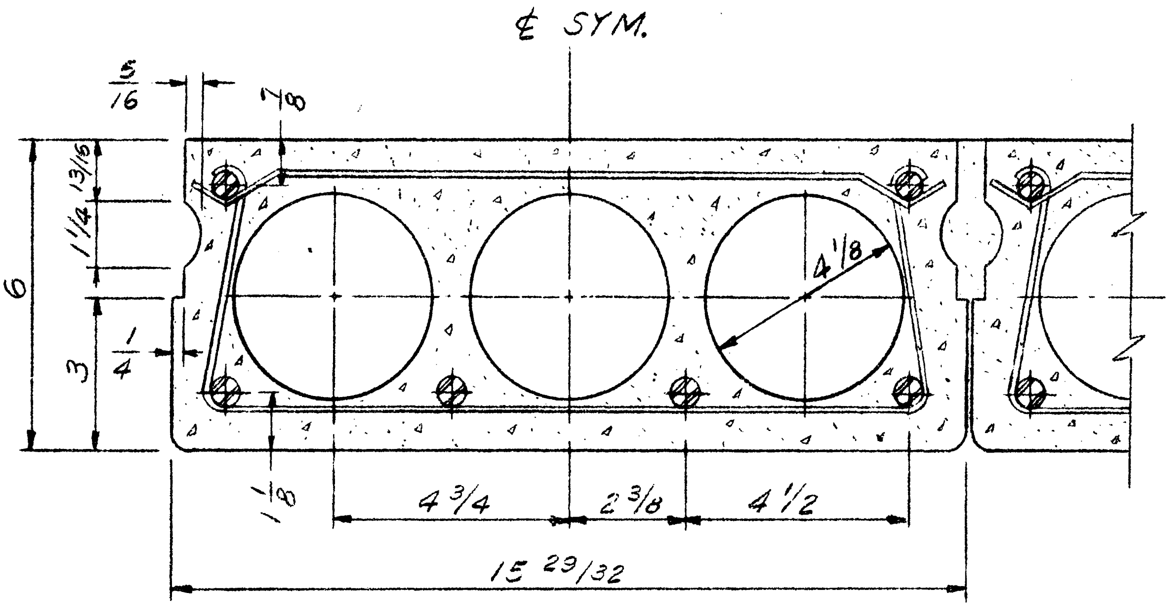
The tests discussed in this report were made to study the structural behavior of Flexicore slabs made of Elastizell concrete. The work was sponsored jointly by Elastizell Corporation of America and the Price Brothers Company, Michigan Flexicore Division. The test specimens were made at the Price Brothers' plant in Livonia, Michigan.

SUMMARY

Four specimens of the Flexicore standard section, designation S44, were made of Elastizell concrete on July 23, 1957 and tested on September 3 and 4. The specimens had been air dried after an initial 12 hour steam cure. The test results indicate that, for most spans and member sizes, Elastizell concrete may be used in Flexicore slabs to reduce dead load and still carry the same allowable live load as when heavy concrete is used. For certain spans, when deflection controls the design, the allowable live load may be slightly less than for the same slab made of heavy concrete. Comparative calculations are shown for the analysis of a Flexicore slab made of stone aggregate concrete and one made of Elastizell concrete. A supplement is included describing the first commercial application of Elastizell concrete to the manufacture of Flexicore slabs.

TEST SPECIMENS

The four test specimens were manufactured at the Flexicore plant in Livonia, Michigan and were of the following cross section:



The Elastizell concrete used in these specimens was proportioned to weigh 110 pcf out of the mixer. However, the unit weight of the concrete in the beams after drying was 120 pcf and in the test cylinders was 115 pcf. This means that with handling and vibration, the Elastizell concrete increased in density by approximately 10 to 15 pcf. This problem can be solved in future work by proportioning the concrete to weigh 10 to 15 pcf lighter at the mixer than is desired in the beam. With handling and vibration, the concrete will increase in weight to yield the desired density in the beam.

The text specimens weighed 9 pounds per lineal foot less than similar beams made with ordinary concrete. This represents a 16% saving in dead load instead of 23% as intended.

The theoretical computations based on the cylinder strengths and moduli are not representative of the concrete in the beams. Past experience has shown that with a 5 pcf increase in density, the strength of this concrete increases 500 psi and the modulus of elasticity increases 285,000 psi. Since the strength and moduli obtained from the cylinders are used in the computations, the allowable loads presented for the beams are somewhat in error on the safe side.

After vibration, the specimens were cured in a low pressure steam kiln for approximately 12 hours. After removal from the forms, the specimens were stored in an outdoor storage area until several days prior to testing.

TEST PROCEDURES

The specimens were placed on simple supports at 12'-0 centers and were loaded with equal concentrated linear loads at the 1/3 points. The following measurements were made at each increment of load.

1. Deflection of specimen at the center line.
2. Strain in the concrete at the center line.

The photographs **in the Appendix show the testing apparatus** and the method of applying load. Photograph No. 1 shows a test specimen after failure in diagonal tension at the far end. The wires leading from the specimen are attached to an SR-4 Strain Gage located on the compression face of the member at the center line. This gage was used to measure the strain in the concrete at each increment of load. A deflection gage is located under the specimen at the center line and was used to measure the deflection of the member at each increment of load. Photograph No. 2 shows in greater detail the method of applying load to the specimens. The rollers beneath the two load beams were not used with Specimen No. 1.

TEST RESULTS

Each specimen was progressively loaded to failure with results as illustrated on Figures 1, 2, and 3 in the Appendix.

SPECIMEN NO. 1

This specimen failed at a total live load of 4,074#. The initial failure was caused by yielding of the steel in the center 1/3 of the beam and was followed by failure of the concrete in compression in the center 1/3. There were no rollers under the load beams at the 1/3 points for this specimen only.

SPECIMEN NO. 2

At a total live load of 3,784#, this specimen failed by yielding of the steel in the center 1/3 of the beam. A diagonal crack formed at 18" from one end of the beam at a total live load of 3,634#, and at failure, this crack was very much advanced.

SPECIMEN NO. 3

This specimen was damaged prior to testing. It was badly cracked on its upper surface, apparently from shrinkage and aggravated by rough handling. A horizontal crack was visible along the middle of the keyway.

The failure of this specimen occurred in diagonal tension at a total load of 3,234# and extended along the horizontal crack in the keyway.

SPECIMEN NO. 4

This specimen also failed in diagonal tension with the center of the diagonal crack 16" from the support. The total live load at failure was 3,584#.

DISCUSSION

As may be seen in the Design Computations on Pages 8, 9, 10, 11 and 12 and also in Figures 1, 2 and 3 in the Appendix, Elastizell concrete may be used in Flexicore slabs. The advantage to be gained from the use of Elastizell concrete in Flexicore slabs is primarily a reduction in the weight of the slabs with no sacrifice of live load. There may actually be an increase in the allowable live load as shown in the Design Computations.

The reduction of dead load in any precast concrete deck system produces economies throughout the structure in which such a system is used. The reduction of dead load in a floor or roof naturally permits a saving in the supporting beams, columns, and footings.

The production of the test specimens at the Livonia plant required no change in the sequence of manufacturing operations nor in the equipment used. For continuous production of Elastizell Flexicore slabs, the only additional equipment required is a foam generation unit which may be operated from the compressed air source presently located in the Livonia plant.

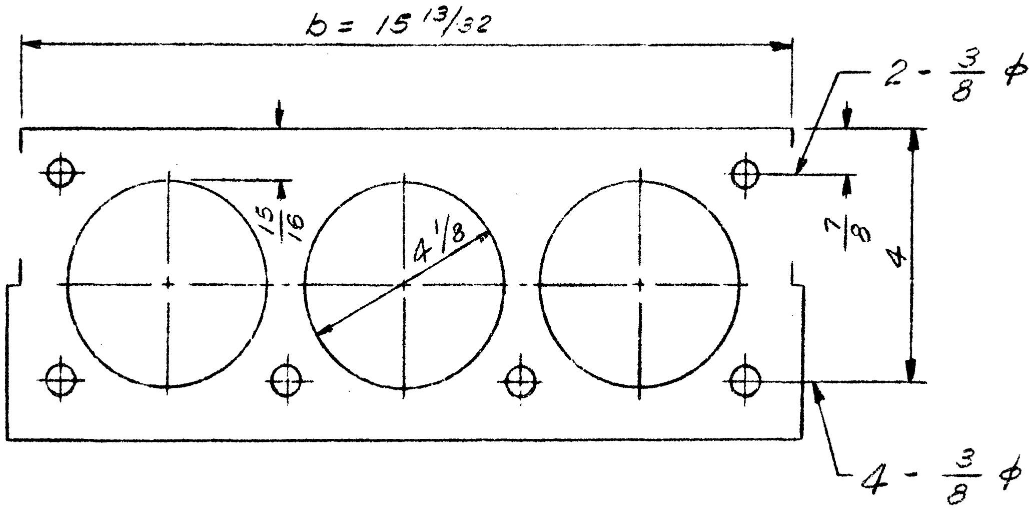
The use of Elastizell concrete in Flexicore slabs normally will require the use of stirrups to a greater extent than is presently required with the use of ordinary concrete. This point is clearly illustrated in the tests. Specimens No. 3 and 4 failed in Diagonal Tension.

The design of Flexicore slabs using Elastizell concrete is identical to that for ordinary concrete except that the proper structural values for Elastizell concrete must be used. These values have been determined by test.

Since Elastizell concrete displays a higher drying shrinkage than ordinary concrete, it may be desirable to use welded wire fabric rather than bars as compressive reinforcement. Properly selected welded wire fabric normally is more effective than bars in controlling shrinkage cracks.

DESIGN COMPUTATIONS

CROSS SECTION OF FLEXICORE SLAB S44



ELASTIZELL **CONCRETE**	REGULAR CONCRETE *
f'_c = 1976 (Avg. 7 Cyl.)	f'_c = 3750 psi
$E_c = 1.75 \times 10^6$ psi (Avg. 2 Cyl.)	$E_c = 3.75 \times 10^6$ psi
n = 17.15	n = 8

SECTION PROPERTIES *

kd = 1.71"	kd = 1.27"
j = .89	j = .91
I = 103 in^4 (Transformed Section)	I = 56.47 in^4

TOTAL ALLOWABLE BENDING MOMENT *

$M_c = \frac{f_c I}{kd}$ = 53,600"#

$M_s = \frac{f_s I}{n c_s}$ = 38,000"# or 3167'#

M_s = 3270'# or 39,250"#

M_s Controls

* Values for Regular
Concrete taken from
Flexicore Tables

ELASTIZELL CONCRETE (continued)	REGULAR CONCRETE (continued)

TOTAL ALLOWABLE SHEAR
(No Web Reinforcing)

$V = v_c bjd$	$V = v_c bjd$
$= (.03)(1976)(3.03)(.89)(4.875)$	$= (.03)(3750)(3.03)4.44$
$= 778\#$	$= 1515\#$

DEAD LOAD CONDITIONS

Wt. of Member = 47.1#/' (Av. of 4 specimens)	Wt. of Member = 56.2#/'
Dead Load Shear = 6 x 47.1 = 282.6#	Dead Load Shear = 6 x 56.2 = 337.2#
Dead Load Moment = $\frac{47.1 \times 144}{8}$	Dead Load Moment = $\frac{56.2 \times 144}{8}$
D. L. M. = 847'#	D. L. M. = 1010'#

LIVE LOAD CONDITIONS

Allowable Live Load Moment:

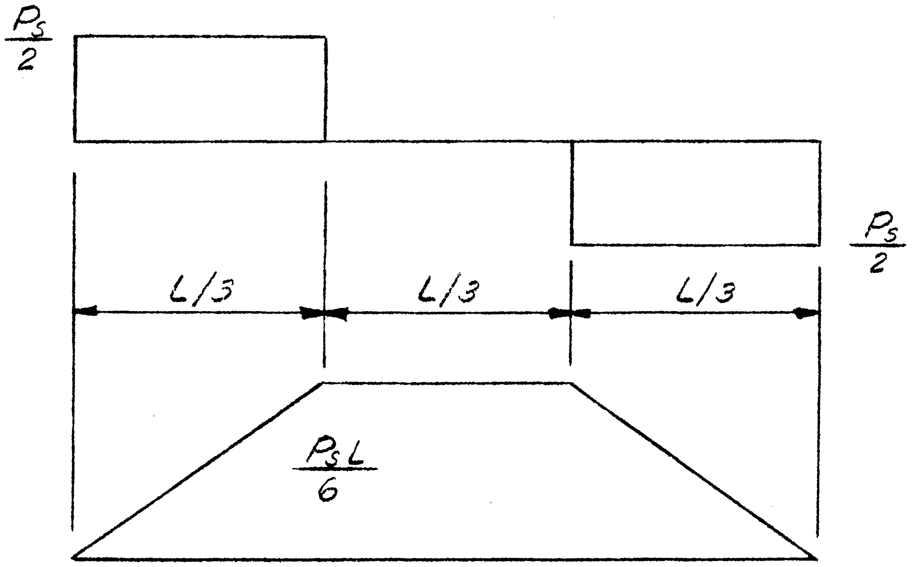
Total Allowable Moment =	3167	Total Allowable Moment =	3270
Dead Load Moment =	- 847	Dead Load Moment =	-1010
Allowable Live Load Moment =	2320'#	Allowable Live Load Moment =	2260'#

Allowable Live Load Shear: (No Web Reinforcing)

Total Allowable Shear =	778	Total Allowable Shear =	1515
Dead Load Shear =	-283	Dead Load Shear =	- 337
Allowable Live Load Shear =	495#	Allowable Live Load Shear =	1178#

ELASTIZELL CONCRETE (continued)	REGULAR CONCRETE (continued)

SHEAR AND MOMENT DIAGRAMS
(LIVE LOAD)



ALLOWABLE THIRD POINT LOADING

Shear:

Elastizell	Regular
$V = \frac{P}{2}$	$V = \frac{P}{2}$
$495 = \frac{P}{2}$	$1178 = \frac{P}{2}$
$P_v = 990\#$	$P_v = 2356$

Moment: (Steel Controls)

Elastizell	Regular
$\frac{P_s L}{6} = 2320$	$\frac{P_s L}{6} = 2260$
$P_s = 1160\#$	$P_s = 1130\#$
<u>Shear Controls</u>	<u>Moment Controls</u>

Assume properly designed web reinforcing.

Then Allowable $P_s = 1160\#$

ELASTIZELL CONCRETE
(continued)

ALLOWABLE UNIFORMLY DISTRIBUTED LOAD

With Web Reinforcing

$W_{LL} = (\frac{8}{L^2})$ (LLM)

$= (\frac{8}{144})(2320)$

$= 129$ #/'

Or

96.7 psf

$V_{LL} = 129 \times 6 = 774$#

$V_{DL} = \underline{283}$

Total V = 1057#

Allowable V = 778 (Page 9)

Stirrups Required for V' = 279#

REGULAR CONCRETE
(continued)

$W_{LL} = (\frac{8}{L^2})$ (LLM)

$= (\frac{8}{144})$ (2260)

$= 125.5$ #/'

Or

94.1 psf

$V_{LL} = 125.5 \times 6 = 753$#

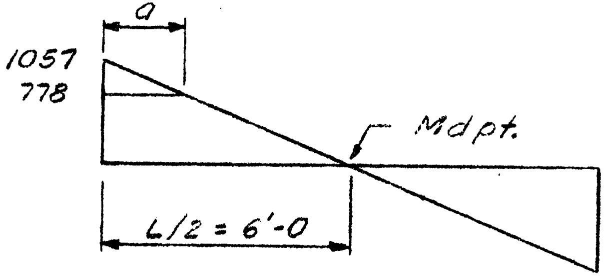
$V_{DL} = \underline{337}$

Total V = 1090#

Allowable V = 1515

No Stirrups Required

Stirrup Details:



$a = (72)\frac{279}{1057} = 19$ "

$d = \underline{4\text{-}7/8"}$

Stirrups
Required for 23-7/8"

$v = \frac{V}{bjd} = \frac{1057}{(3.03)(.89)(4.875)} = 80.5$ psi

ELASTIZELL CONCRETE (continued)

REGULAR CONCRETE (continued)

$80.5 = .041 f'_c < 0.06 f'_c$

Maximum spacing $= \frac{d}{2} = 2.44$

Say 2-3/8"

$$A_v = \frac{V's}{f_v jd} = \frac{279 \times 2.375}{20000 \times .89 \times 4.875}$$

$= .00764$ sq. in.

or

$A_v = (.0015)(3.03)(2.375)$

$= .01078$ sq. in. Controls --- (ACI 807)

Use 11 - #13 wire U stirrups

at 2-3/8" centers at each end.

CONCLUSION

The following conclusions summarize the results of the tests on which this report is based.

1. Elastizell concrete may be used in Flexicore slabs without decreasing the allowable live load of the slabs. For specific spans it may be found that deflection controls the design in which case the allowable live load may be somewhat less when Elastizell concrete is used.
2. The use of Elastizell concrete in Flexicore slabs would reduce the unit weight of these slabs.

3. No changes would be required in the manufacturing sequence or in the equipment used. It would be necessary to install a foam generation unit which can be operated from the existing source of compressed air.
4. Only minor changes need be made in fabrication. Such changes would include the increased use of stirrups and possibly the use of welded wire fabric in place of deformed bars for compressive reinforcement.
5. Elastizell concrete increases in density with handling and vibration. Surplus air must be added at the mixer to allow for this loss of air.

SUPPLEMENT

Since the preparation of the foregoing report the first commercial application of Elastizell concrete for Flexicore slabs has been completed. It consisted of a roof system for a 3500 sq. ft. residence. The maximum span was 26 ft. with other spans varying from approximately 12 ft. to 18 ft. The slabs were manufactured at the Price Brothers Company's Michigan Flexicore Division. The work included both 6" x 16" and 8" x 16" sections.

The previous tests of Flexicore slabs made with Elastizell concrete showed that the concrete would increase in density during handling and vibrating. Based on a study of those test results, the mix for these members was proportioned to give 100 pcf concrete at the mixer, with the expectation that the wet density after placing and vibrating would be 115 pcf which would yield a final dry density of 110 pcf.

The mix was designed to yield a concrete weighing 110 pcf dry, having a compressive strength of 2000 psi at 28 days and a modulus of elasticity of 1.75×10^6 psi. The cement content was 7 sacks per cu. yd. at a density of 110 pcf wet. Test cylinders were made at random intervals during the operation and vibrated with the slabs.

The test cylinders were weighed, measured and broken at 7, 8 and 9 days after pouring to determine whether the concrete was sufficiently cured to permit shipping the slabs. The test results are shown in the following table.

Cyl. No.	Date Poured	Date Tested	Age at Test, Days	Air Dry Density at Test Date, pcf	Compressive Strength, psi
1	10-9-57	10-18-57	9	109.2	1830
1A	10-9-57	10-18-57	9	113.0	2640
X*	10-9-57	10-18-57	9	110.5	2495
XA*	10-9-57	10-18-57	9	113.5	2595
2	10-10-57	10-18-57	8	107.3	1823
2A	10-10-57	10-18-57	8	108.3	2015
3	10-10-57	10-18-57	8	109.0	2075
3A	10-10-57	10-18-57	8	107.0	2010
4	10-11-57	10-18-57	7	111.0	2370
4A	10-11-57	10-18-57	7	112.3	2080

* These batches had double the usual amount of dispersing agent.

The following two production problems, neither of which is serious, were encountered in the manufacture of these slabs.

1. The greater fluidity of the Elastizell concrete requires a tight fitting gate on the bucket used to transport the concrete from mixer to forms.
2. The usual production procedure used in this plant required that the rubber core tubes be removed in about 4 hours for reuse. Since the Elastizell concrete has a somewhat longer setting time it had to be accelerated if it

was to conform to the usual production plan. It was found that the set could be sufficiently accelerated by turning off the vapor jets in the kiln for about 1-1/2 hours immediately after placing the slabs in the kiln. However, care must be taken to prevent too rapid drying during this period.

After the initial steam curing period the members should be protected from extremes of weather conditions. This is equally true of members made of regular dense concrete. The Elastizell concrete members for this job were kept moist in the yard for about a week.

This first commercial application of Elastizell concrete to Flexicore slabs has demonstrated that it is possible to make lightweight Flexicore slabs on a production basis using Elastizell concrete. The obvious advantages to be gained are

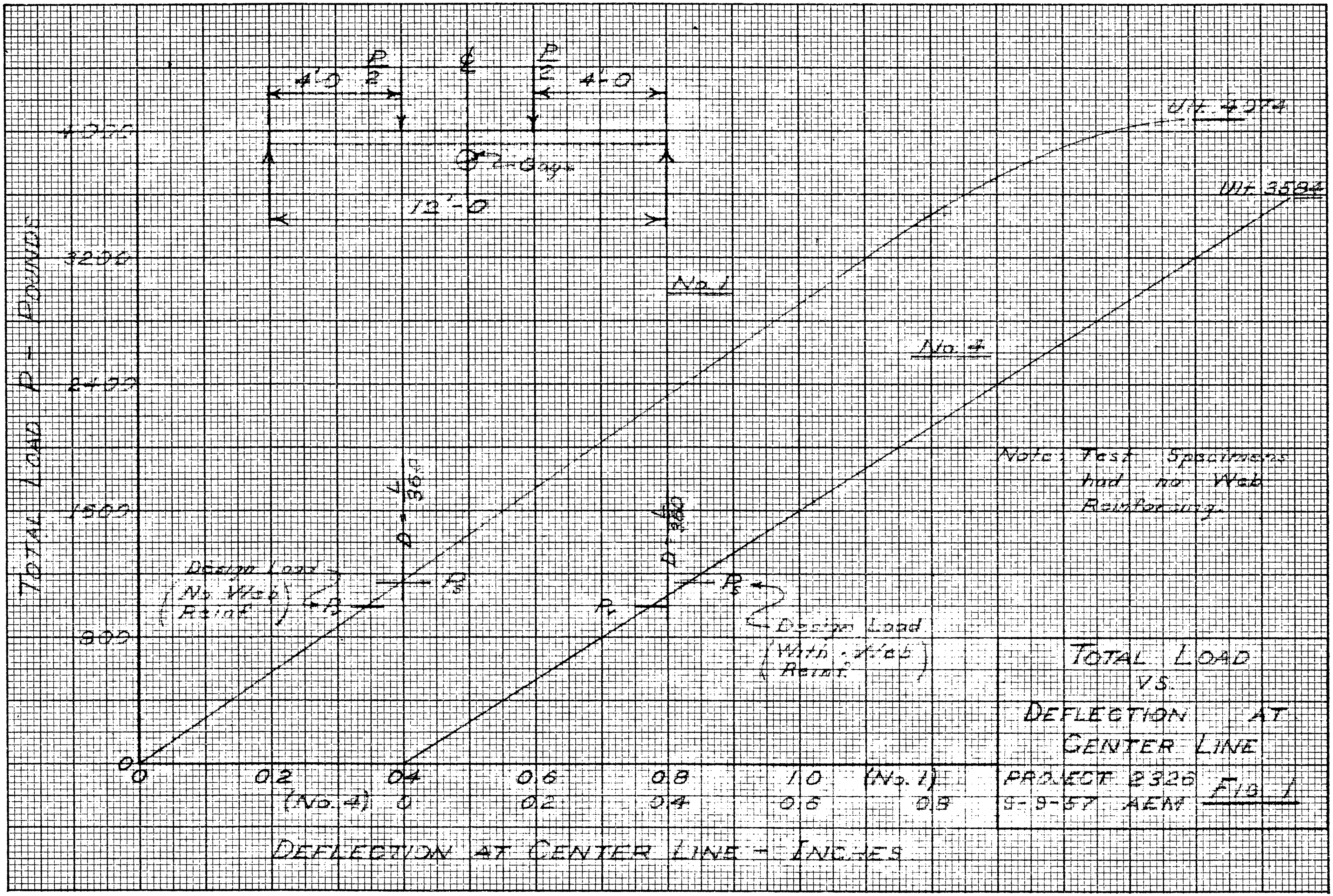
1. A 25% reduction in weight of members, with no reduction in live load capacity.
2. A 45% decrease in thermal conductivity.
3. Manufacture of lightweight structural grade concrete without the use of lightweight aggregates.

APPENDIX

The design loads shown on Figures 1, 2, and 3 are (1) P_s = 1160# = the sum of 2 equal 1/3 point loads which would cause a calculated stress of 20,000 psi in the positive reinforcement and (2) P_v = 990# = the sum of 2 equal 1/3 point loads which would cause a calculated diagonal tension stress of 59.3 psi in the concrete adjacent to the supports.

Figures 1 and 2: Total Load vs. Deflection at the Center Line - These figures show the relationship of total load to measured deflection at mid span. The equation $D = L/360$ is shown on each curve to indicate the actual loading at which the live load deflection at mid span was equal to 1/360 of the span.

Figure 3: Total Load vs. Strain in Concrete at Center Line - This figure shows the relationship of total load to measured strain in the concrete at the center of the span. The symbol f_c is shown on each curve to indicate the actual loading at which the maximum stress in the concrete was equal to 0.45 of the compressive strength of the concrete.

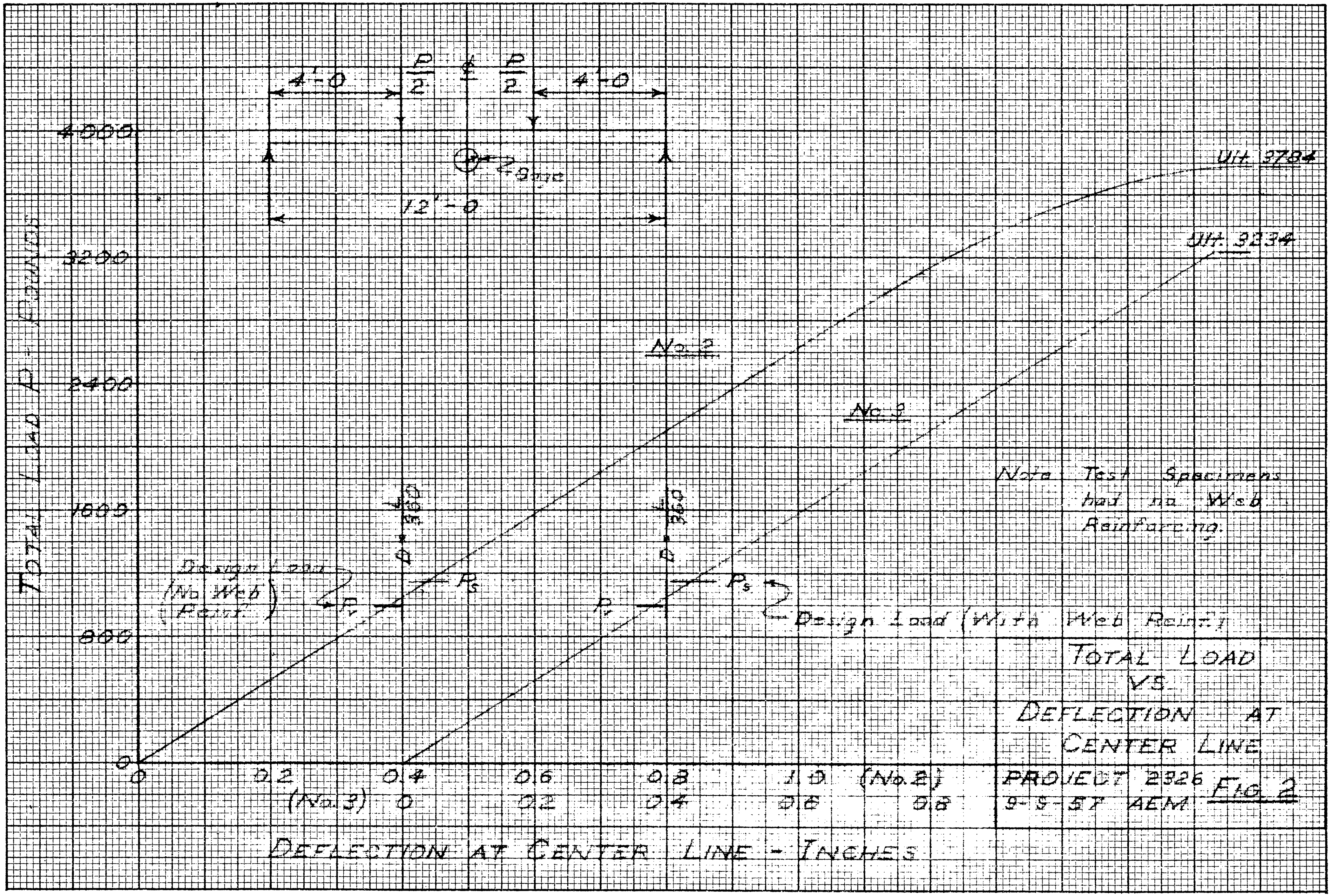


TOTAL LOAD VS. DEFLECTION AT CENTER LINE

PROJECT 2326
9-9-57 AEM

FIG. 1

Note: Test Specimens had no Web Reinforcing.

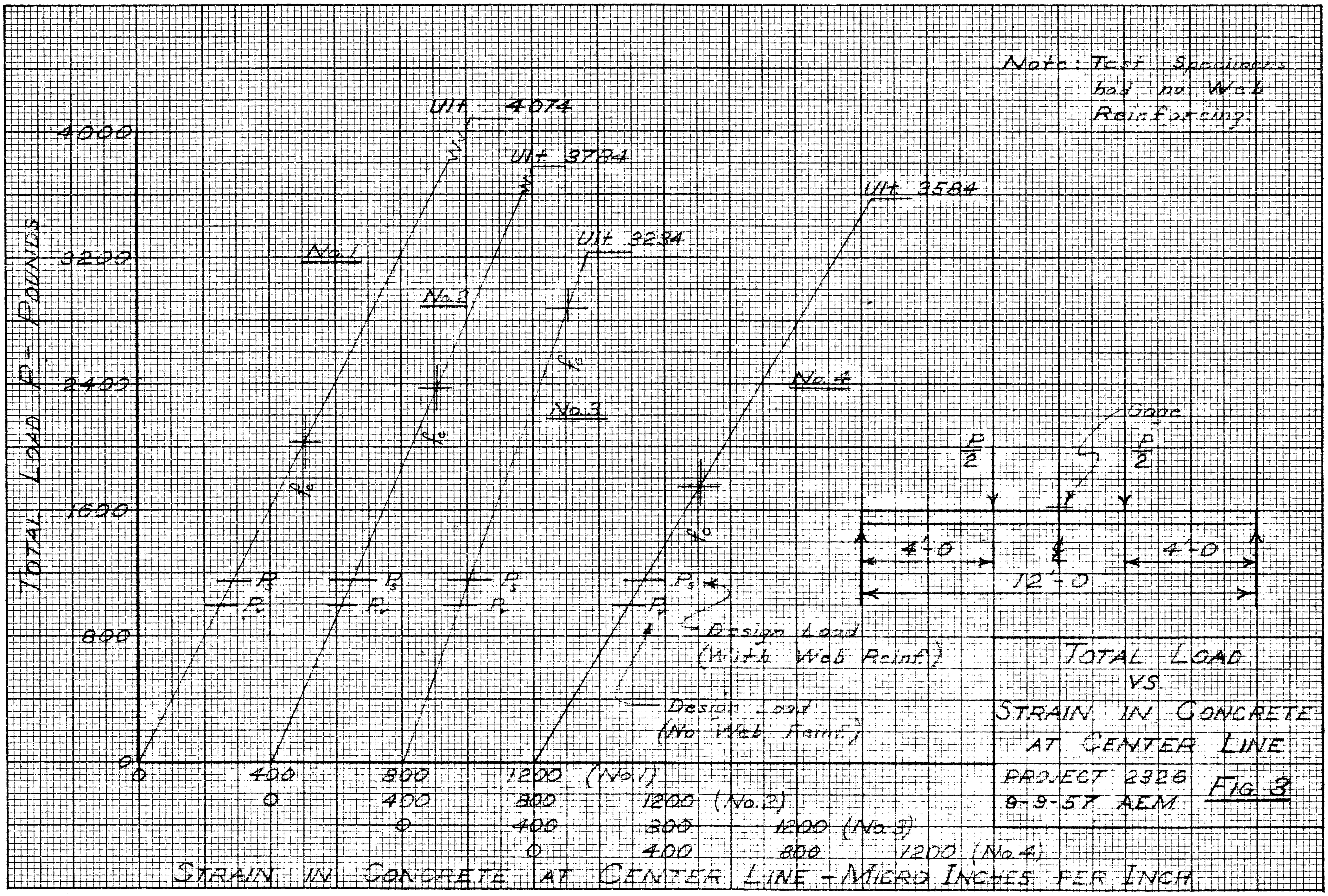


TOTAL LOAD VS DEFLECTION AT CENTER LINE

PROJECT 2326

9-9-57 AEM

FIG 2



TOTAL LOAD
VS
STRAIN IN CONCRETE
AT CENTER LINE

PROJECT 2326
9-9-57 AEM

FIG. 3

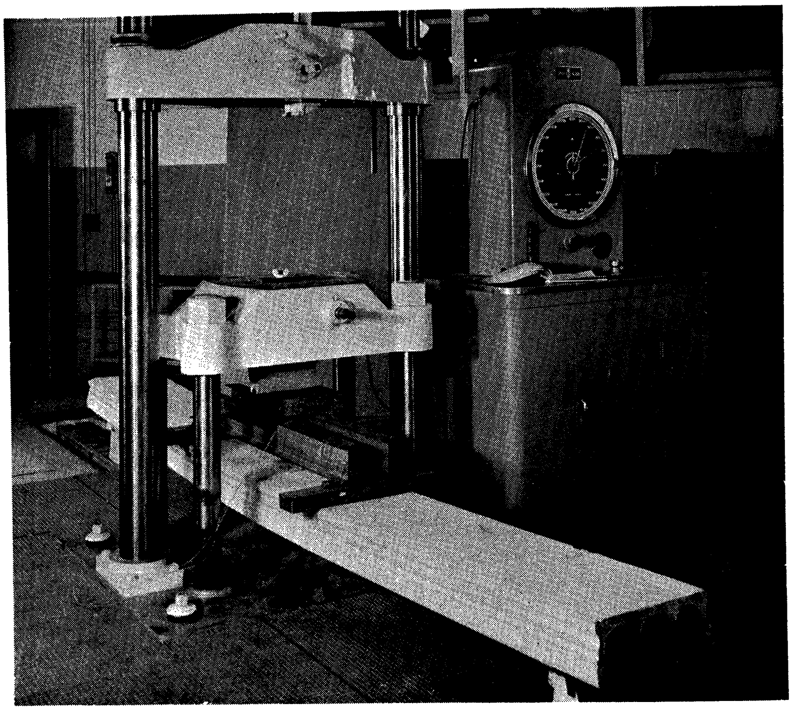


Photo. 1. Test Specimen after Failure.

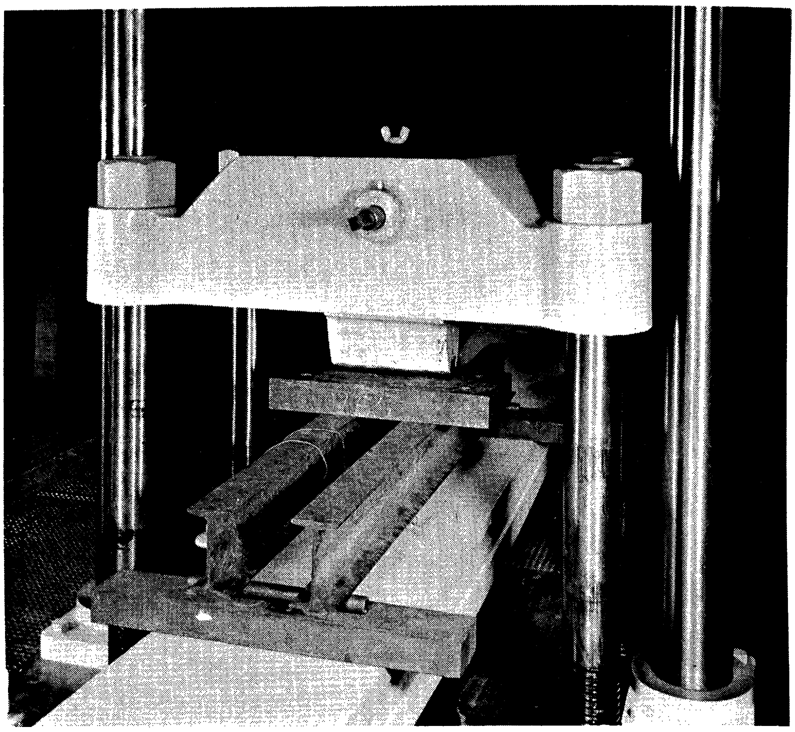


Photo. 2. View of Loading System.