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Tests of Reinforced Concrete Beams: Resistance to Web Stresses

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TESTS OF REINFORCED CONCRETE BEAMS: RESISTANCE TO WEB STRESSES

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED TESTS OF REINFORCED-CONCRETE BEAMS:

RESISTANCE TO WEB STRESSES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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CONTENTS

I INTRODUCTION.

Ever since reinforced concrete has come into such universal use as a building material, differenttheories have been advanced concerning the action of reinforced concrete beams. Many experiments have been made an d careful study has been carried on at different places under the supervision of commisioners amd committees organized for that purpose. The University of Illinois Engineering Experiment Station, under the direct supervision of Professor A. N. Talbot has taken the lead in the experimental work conducted on concrete beams and columns, and the theories advanced have been universally accepted. From the time of the establishment of the Engineering Experiment Station, tests of a general nature have been made on beams, comparing the effect of various mixtures of concrete, the variation of percentage of reinforcement, and although some of the failures in these tests were caused by diagonal tension, yet a study of this particular stress was not taken up until two years ago when a thesis was prepared by Phipps and Whipple on "A Study of Diagonal Tension Failures". A year later a study of web stresses was again taken up with the particualr purpose in view of determining the effect of different methodsof web reinforcement.

In this thesis the object is to continue the study of diagonal tension failures already begun. Additional data were secured to make the past thesis more complete so the comparisons could be more fully made.

In order to make the data more complete, tests were made on beams varying in span, age, and in horizontal and vertical reinforcement. A total of fifty beams were tested.

The different beams were divided into three classes, A, B, and C, in order to make a more careful study of the results. Class A consists of all beams of 6 ft. span, containing only longitudinal reinforcement. These were tested at ages varying from 14 to 60 days. The mixtures varied from a rich concrete of 1 - 1 - 2 to a lean mixture of 1 - 5 - 10 and the longitudinal reinforcement varied from 0.98 per cent to 2.21 per cent. Class B contains all beams of 8 ft., 10 ft., and 12 ft. spans with only longitudinal reinforcment. The mixtures were the same throughout, 1 - 2 - 4 but the steel reinforcement and ages varied. The results secured from this class offer good comparison with class A as to the effect of length under the same conditions of loading. Class C consists of all the beams of 6 ft. span, containing web reinforcement. The age and mixtures were constant but the horizontal and web reinforcement varied. The comparisons of the data of class C with those of class A form the primary object of the thesis, for the direct comparisons are made from the effect on strength developed between beams with web reinforcement and those without when all other conditions are similar.

Tables have been arranged which contain all the data concerning the manufacture of the beams, the compressive stress in the concrete, the tensile stress in the steel

the bond stress and, most important of all for this investigation, the stresses due to diagonal tension. Curves have been plotted showing the deflection, the deformation and range of neutral axis, with respect to the applied loads. In preparing these tables and curves it has been the special purpose to set forth all data of particular interest in the study of failure of beams due to diagonal tension.

All tests were made in the Laboratory of Applied Mechanics in connection with the experiments on concrete, carried on by the University of Illinois Engineering Experiment Station.

II THEORY AND AVAILABLE DATA.

Preliminary In the design of reinforced concrete beams, the web stresses play an important part. If beam action exists, the stresses in the upper and lower fibers must be transferred from one to the other through the web. This gives rise to three kinds of stresses in the web of the beam, namely, those due to the tendency for the longitudinal reinforcing bars to slip through the concrete, those due to the shear in the concrete, and those due to the combination of the shear and the tension in the concrete. These stresses are called bond, shear, and diagonal tension stresses respectively.

Theory Professor A. N. Talbot derives the following formula for computing the bond stress in the longitudinal reinforcement,

$$u = \frac{V}{mod'}$$

in which u represents the bond developed per unit of area of surface of the bar, V is the total external vertical shear, m is the number of reinforcing bars, o is the circumference or periphery of one bar, and d' is the distance from the center of the longitudinal reinforcement of the centroid of the compressive stresses.

Transposing the above equation we have,

$$umo = \frac{V}{d'}$$

which is the stress, for a unit length of beam, transferred to the concrete by the longitudinal reinforcing bars. Consider this distributed over a horizontal section just above the plane of the bars for a unit length of the beam, and call the horizontal shearing unit-stress v. The resistance to the horizontal shear then developed per unit length of the beam is bv, in which b is the width of the beam. Equating this to mou, we have,

$$v = \frac{V}{bd'} .$$

In mechanics it is shown that the horizontal unit-shear is equal to the vertical unit-shear; hence we have the vertical shearing unit-stress at a point just above the plane of the longitudinal reinforcement. If the tension in the concrete is neglected, the unit-shear will be uniform up to the neutral axis.

It has been shown that

$$t = \frac{1}{2}s\sqrt{\frac{1}{4}s^2 + v^2}$$

where t is the diagonal tensile unit-stress in the concrete, s is the horizontal tensile unit-stress in the concrete, and v is the horizontal or vertical shearing unit-stress in the concrete. This line of maximum tension makes an angle with the horizontal equal to one half the angle whose cotangent is $\frac{s}{2v}$. Neglecting the tension in the concrete the formula for the diagonal tension reduces to

$$t = v$$

and the angle that the line of maximum diagonal tension

makes with the horizontal becomes 45 degrees. Because of the difficulty of computing the actual amount of the horizontal tensile stress in the concrete, it is generally considered best to compute the horizontal and vertical shearing unit-stress and make all comparisons on the basis of this value. This method will beadopted in these investigations.

Considering that the vertical stirrups are used, and that the test has passed the point where the concrete of the web resists the diagonal tension, we may count on the stirrups taking all the vertical component of this stress. The amount of this vertical component, per unit length of beam, is equal to the horizontal unit-shear multiplied by the width of the beam. If the stirrups are spaced at a distance X apart, the stress carried by the two prongs of the stirrup will be Xvb. Hence if s equals the stress in one prong,

$$s = \frac{Xbv}{2} = \frac{Vx}{2d'}$$

In computing the bond in any stirrup, only that part of the stirrup which lies above the neutral axis should be considered, for bond action below the neutral axis ceases when the cracks open up.

There are several other theories which have been used to furnish formulae for the computation of the stresses in the stirrups of beams; but, as the theory developed by Professor Talbot is considered to be the most rational the others will not be considered here.

In computing the tensile stresses in the longitudinal reinforcement, the formula $f_s = \frac{M}{Ad'}$

will be used, and in computing the compressive stresses in the concrete the formula ,

$$f_c = \frac{3(2 - q) M}{(3 - q)d'Kbd}$$

will be used. In these formulae d' will be taken as 8.7 -in. K as .35 and q as 1.

Available Data From the tests of reinforced beams of the series of 1906, the following values of the vertical shearing unit-strength were obtained:

1 - 2 - 4 concrete - - - - - - - 136 to 142 lb. per sq. in.
Av. 139 lb. per sq.in.

1 - 3 - 6 concrete - - - - - 92 to 115 lb. per s . in.
Av. 99 lb. per sq. in.

1 - 3 - 6 poorly made concrete 55 to 83 lb. per sq. in
Av. 69 lb. per sq. in.

1 - 5 - 10 concrete - - - - - - - 63 to 74 lb. per sq. in.
Av. 68 lb. per sq. in.

III MATERIALS AND METHOD OF TESTING.

Materials The materials used in making the beams were generally purchased in the open market, in order that they might conform to those ordinarily obtained in practice. The Universal cement and the corrugated bars were furnished by the manufacturers; the round mild steel was furnished by the Illinois Steel Company, Chicago, Illinois.

Stone The stone for the tests was a good quality of lime-stone from Kankakee, Illinois. It was ordered screened through a 1 -in. screen and over 1/4-in. screen. The stone contained about 55 per cent of voids and weighed 80 lb. per cu. ft. In the determination of the voids in the stone, three tests were made and an average value found. Care was taken that no air was caught in the box while the material was being poured into the water.

Table 1 gives the results of a mechanical analysis of the stone.

TABLE 1

Mechanical Analysis of Stone.

Sieve	Per cent Passing.
1-in.	100
3/4-in.	89.2
1/2-in.	54.7
3/8-in.	32.8
No. 3	16.9
No. 5	4.1
No. 10	2.5

Sand The sand used came from near the Wabash river at Attica, Indiana. It was of good quality, well graded and fairly clean. It weighed 101 lb. per cu. ft. loose and contained 28 per cent voids.

Table 2 gives the average results of several mechanical analyses of this sand, the samples being taken at intervals throughout the season.

TABLE 2

Mechanical Analysis of Sand.

Sieve No.	Per cent Passing
3	99.2
5	89.0
10	64.7
12	57.8
16	49.9
18	39.0
30	21.6
40	11.8
50	5.1
74	2.6
150	0.46

Cement With a few exceptions Chicago A A Portland Cement was the brand used in the manufacture of the beams. The other brand used was Universal Portland.

Table 3 gives the results of a mechanical analysis of the cement.

TABLE 3

Mechanical Analysis of Cement.

Sieve No.	Per cent Passing	
	Chicago A A	Universal
75	98.3	99.3
100	95.1	98.5
200	80.6	90.1

The tensile strength of these cements, as determined by the briquettes made by standard methods, is given in Table 4. The values given are the averages obtained from tests made at different intervals.

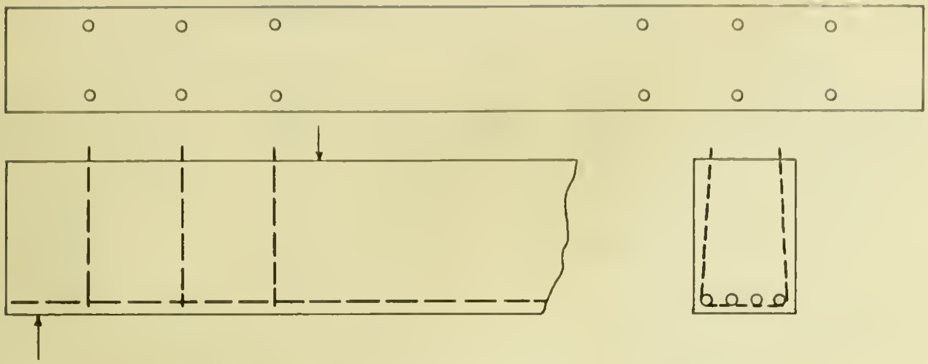
TABLE 4.

Tensile Strength of Cement.

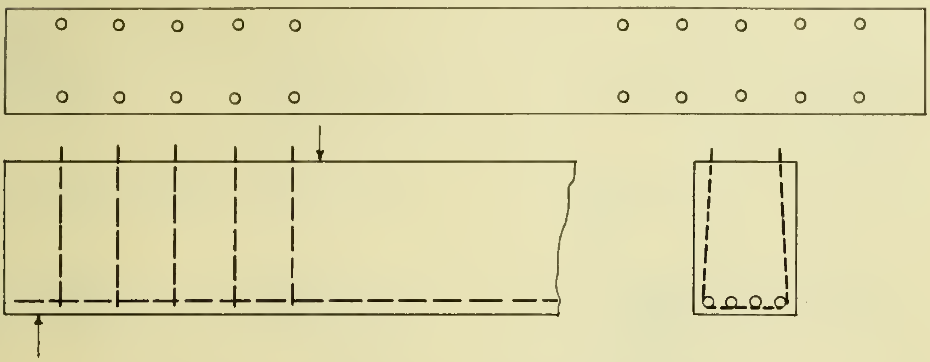
Cement	Ultimate Strength lb. per sq. in. 7 days Neat	7 days 1-3	28 days Neat	28 days 1-3
Chicago A A	666	182	792	284
Chicago A A	811	227	833	307
Chicago A A	665	175	799	266
Chicago A A	732	192	857	318
Chicago A A	559	145	707	247
Average	693	184	798	284
Universal	699	242	754	292
Universal	728	232	776	285
Universal	809	248	885	336
Universal	563	244	764	319
Average	700	242	795	308

Steel The longitudinal reinforcement used consists of 1/2-in., 3/4-in. and 1-in. mild-steel, plain round rods, and of 1/2-in. and 3/4-in. high-steel Johnson corrugated bars. For the stirrups 1/4-in. and 1/2-in. plain round mild-steel rods were used. Table 5 gives the results of the tensile tests of these rods, the samples tested being cut from the ends left after the bars were cut for the beams. These results are the averages of tests made on several specimens from the reinforcement of each beam.

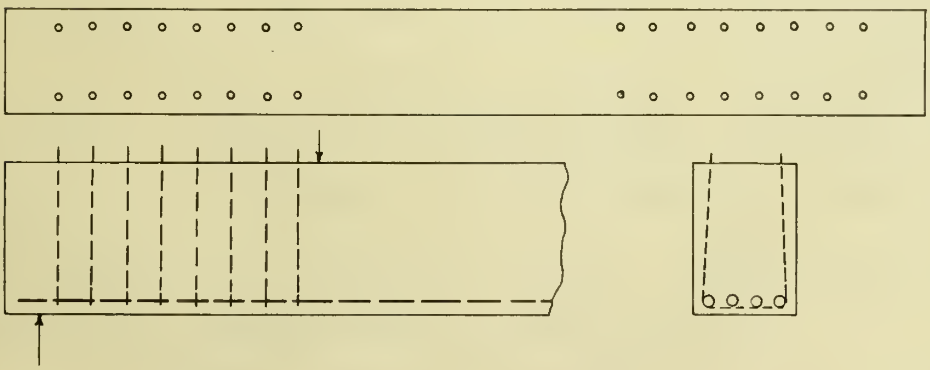
The corrugated bars were furnished by the Expanded Metal and Corrugated Bar Company, St. Louis, Mo., and the plain bars by the Illinois Steel Company, Chicago, Illinois.



1/2-in. Stirrups spaced 8-in.



1/2-in. Stirrups spaced 5-in.



1/4-in. Stirrups spaced 3-in.

PLATE I.

Method of Placing Reinforcement

Vertical and Horizontal

TABLE 5.

Tensile Strength of Steel Reinforcement.

Kind of Reinforcement	Per cent elong. in 8 ins.	Load lb. per sq. in. Yield Point	Ultimate Load
Longitudinal			
~~1/2-in. mild~~ round steel	27 to 33	40190	60980
1/2-in. corrugated high steel	15 to 25	48220	79110
3/4-in. corrugated high steel	11 to 12	53400	89100
Stirrups			
1/2-in round mild steel	25 to 30	41000	61750
1/2-in. corrugated high steel	24 to 30	33600	55900
1/4-in. round mild steel	6 to 20	63740	73460

Concrete Table 6 gives the results of compression tests of 6-in, concrete cubes. The concrete used in making the cubes was taken from the mix used in making a test beam. The number of the test beam corresponding to the cubes is given in the first column. After the forms were removed the cubes were stored in damp sand. The compressive strength given for the concrete in each beam is the average value obtained from the tests of three cubes.

TABLE 6.

Compressive Tests of 6-in. Concrete Cubes.

Ref. No.	Age in Days	Compressive strength in lb. per sq. in.	Mixture by by Volume	Mixture by Weight
218.2	59	2670	1-2-4	1:2.59:4.22
219.2	67	2670	1-2-4	1:2.59:4.22
220.2	59	2328	1-2-4	1:2.54:4.25
220.5	58	2210	1-2-4	1:2.66:4.43
217.0	61	3000	1-2-4	1:2.42:4.12
217.1	15	1175	1-2-4	1:2.55:4.15
217.2	66	2163	1-2-4	1:2.55:4.15
217.4	69	2913	1-2-4	1:2.61:4.32
252.6	59	3055	1-2-4	1:2.53:4.30
252.7	59	2328	1-2-4	1:2.54:4.25
210.1	65	3956	1-1-2	1:1.33:2.18
210.2	70	5188	1-1-2	1:1.27:2.11
210.3	63	3566	1-1-2	1:1.18:2.08
211.4	64	3282	1-1 1/2-3	1:1.90:3.15
213.3	65	1688	1-3-6	1:3.42:5.70
213.4	65	1118	1-3-6	1:3.93:6.57
214.4	68	1305	1-4-8	1:4.83:8.23
215.3	64	1096	1-5-10	1:5.75:9.61
215.4	69	1175	1-5-10	1:6.09:10.05
215.5	60	902	1-5-10	1:6.64:11.11
240.2	59	1783	1-2-4	1:2.65:4.38
256.1	68	2233	1-2-4	1:2.63:4.39
256.2	61	2458	1-2-4	1:2.57:4.25
254.1	67	2103	1-2-4	1:2.61:4.38
253.1	59	3055	1-2-4	1:2.60:4.18
253.5	65	3660	1-2-4	1:2.60:4.26
253.6	59	3055	1-2-4	1:2.53:4.30
221.3	57	2263	1-2-4	1:2.39:3.98
221.4	62	1787	1-2-4	1:2.20:3.98
223.2	57	2263	1-2-4	1:2.39:3.98
223.3	62	1787	1-2-4	1:2.20:3.98
240.1	62	2613	1-2-4	1:2.46:4.05
243.3	57	1787	1-2-4	1:2.46:4.05
243.4	59	1783	1-2-4	1:2.65:4.38
229.1	61	3000	1-2-4	1:2.42:4.11

Test Beams. In all the tests herein discussed the cross section of the beams was 8-in. by 11-in., the center of the steel being placed 10-in. below the top surface. The test spans varied from 6 ft. to 12 ft. The reinforcing bars were straight and were placed horizontally throughout the beam. Vertical stirrups were used in several beams.

The sizes used were 1/2-in. and 1/4-in. plain round rods. These stirrups were placed from 3-in. to 8-in. apart longitudinally throughout the outer third of the span length. They were U-shaped and passed under all the reinforcing bars and extended through the top surface of the beam. The position of the stirrups is shown in Plate I. In two of the test beams the longitudinal reinforcing bars were anchored at each end with a 2 1/2-in. cut washer, held in place by nuts on each side. In another beam the reinforcement used was an imitation of the Kahn bar. For data of manufacture on all beams see Table 7.

TABLE 7.

General Data on Beams

Beam No.	Kind of Concrete	Reinforcement Per Cent	Reinforcement Amount and Disposition	Span ft.	Age in Days
218.1	1-2-4	0.98	4 1/2-in. plain round	6	64
218.2	1-2-4	0.98	4 1/2-in. plain round	6	67
218.3	1-2-4	0.98	4 1/2-in. plain round	6	46
218.4	1-2-4	0.98	4 1/2-in. plain round	6	61
219.1	1-2-4	1.46	6 1/2-in. plain round	6	65
219.2	1-2-4	1.46	6 1/2-in. plain round	6	67
220.1	1-2-4	2.21	4 3/4-in. plain round	6	68
220.2	1-2-4	2.21	4 3/4-in. plain round	6	66
✕220.5	1-2-4	1.96	2 1-in. plain round	6	36
217.5	1-2-4	0.98	4 1/2-in. plain round	6	36
217.0	1-2-4	0.98	4 1/2-in. plain round	6	14
217.1	1-2-4	0.98	4 1/2-in. plain round	6	15
217.2	1-2-4	0.98	4 1/2-in.plain round	6	63
217.3	1-2-4	0.98	4 1/2-in. plain round	6	32
217.4	1-2-4	0.98	4 1/2-in. plain round	6	81
252.6	1-2-4	1.25	4 1/2-in. sq. cor.h.s.	6	66
✕252.7	1-2-4	1.25	4 1/2-in. sq. cor.h.s.	6	64
✕252.5	1-2-4	1.25	4 1/2-in. sq. cor.h.s.	6	66
210.1	1-1-2	0.98	4 1/2-in. plain round	6	63
210.2	1-1-2	0.98	4 1/2-in. plain round	6	72
210.3	1-1-2	0.98	4 1/2-in. plain round	6	60
211.4	1-1 1/2-3	0.98	4 1/2-in. plain round	6	63
211.5	1-1 1/2-3	0.98	4 1/2 in. plain round	6	72
213.3	1-3-6	0.98	4 1/2-in. plain round	6	68
213.4	1-3-6	0.98	4 1/2-in. plain round	6	67
214.3	1-4-8	0.98	4 1/2-in. plain round	6	67
214.4	1-4-8	0.98	4 1/2-in. plain round	6	73
214.5	1-4-8	0.98	4 1/2-in. plain round	6	64
215.3	1-5-10	0.98	4 1/2-in. plain round	6	67
215.4	1-5-10	0.98	4 1/2-in. plain round	6	71
215.5	1-5-10	0.98	4 1/2-in. plain round	6	67
⊙240.2	1-2-4	1.66	3 3/4-in. plain round	6	64
256.1	1-2-4	2.21	4 3/4-in. plain round	12	64
256.2	1-2-4	2.21	4 3/4-in. plain round	12	71
255.1	1-2-4	1.67	3 3/4-in, plain round	10	63
255.2	1-2-4	1.71	7 1/2-in. plain round	10	63
254.1	1-2-4	1.23	5 1/2-in. plain round	8	63
254.2	1-2-4	1.23	5 1/2-in. plain round	8	75
253.1	1-2-4	✕2.81	4 3/4-in. sq. cor. h.s.	12	67
✕253.5	1-2-4	1.25	4 1/2-in. sq. cor.h.s.	12	66
✕253.6	1-2-4	1.25	4 1/2-in. sq. cor.h.s.	6	64
·221.3	1-2-4	1.66	3 3/4-in. plain round	6	57
·221.4	1-2-4	1.66	3 3/4-in. plain round	6	70
···223.2	1-2-4	1.23	5 1/2-in. plain round	6	57
··223.3	1-2-4	1.23	5 1/2-in. plain round	6	70
·⊙240.1	1-2-4	1.66	3 3/4-in. plain round	6	60
··243.3	1-2-4	1.25	4 1/2-in. sq. cor.h.s.	6	64
··243.4	1-2-4	1.25	4 1/2-in. sq. cor.h.s.	6	64
·□229.1	1-2-4	1.23	5 1/2-in. plain round	6	63
522.1	1-2-4	1.25	Im.Kahn reinforce.	6	60

✕ Universal Cement □ Stirrups at one end only

⊙ Two 1/2-in. washers held by nuts on both sides. (see next page.)

· 1/2-in. stirrups spaced 5 in. apart.

·· 1/2 -in stirrups spaced 8 in. apart..

··· 1/4 - in. stirrups spaced 3 in. apart

Making of the Beams The beams were made directly on the concrete floor of the laboratory, a strip of building paper being laid beneath the forms which were of ordinary wooden knockdown type. The forms were removed seven days after making the beams and the beams were not moved from their position of the floor until the time of test. Generally the stone for the concrete was dampened and and the concrete well mixed and wet enough to secure proper hardening. The making of the beam was done by men skilled in concrete work. In nearly all cases two beams were made from the same mix of concrete. In order however, to give the tests a greater range of conditions, no two beams of the same set were made or tested at the same time. The beams were stored in a room the temperature of which varied from 55 degrees F. to 65 degrees F. The age at which they were tested varied from 14 to 81 days. The majority of the beams being tested at the end of about 60 days.

Method of Testing The beams were all tested in the 200000-lb. Olsen testing machine and in nearly all cases were loaded at the 1/3-points. The method used for loading at the 1/3-points is shown in Plate II. The supports of the beam allowed longitudinal movement, the bottom being on an arc of 12-in. radius, and the top, on which cast iron blocks rested having a radius of 1 1/2-in. Turned steel rollers, two inches in diameter were used for applying the loads at the third points. Between these rollers and the I-beams

through which the load was applied, blocks were placed, one being a rocker block to allow for the lateral adjustment. The blocks at the supports and load points were cushioned with a sheet of rubber about 1/8-in. thick.

Center ~~of~~ deflections were read on all beams. On all beams over 6 feet in length deformation of the upper fiber and steel were measured by means of four extensometers, which were placed on the beam as shown in Plate III.

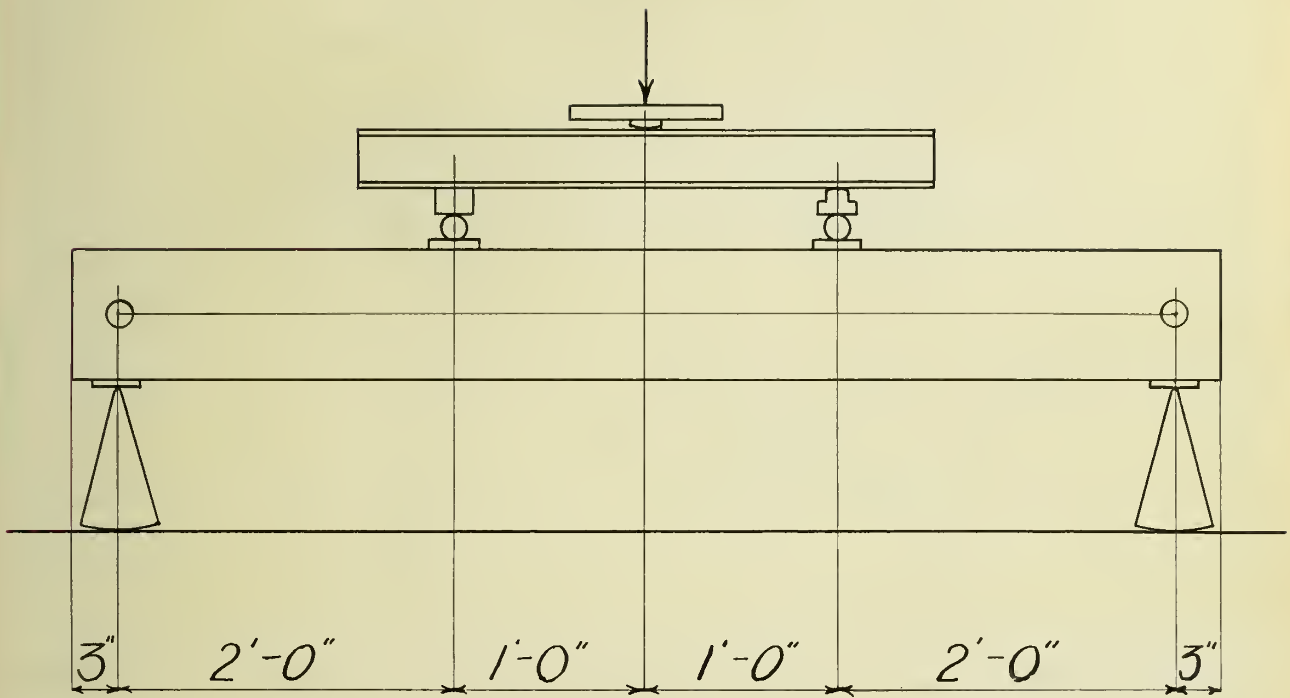


PLATE II.

Arrangement of Apparatus and Method of Loading

6-ft. Beams.

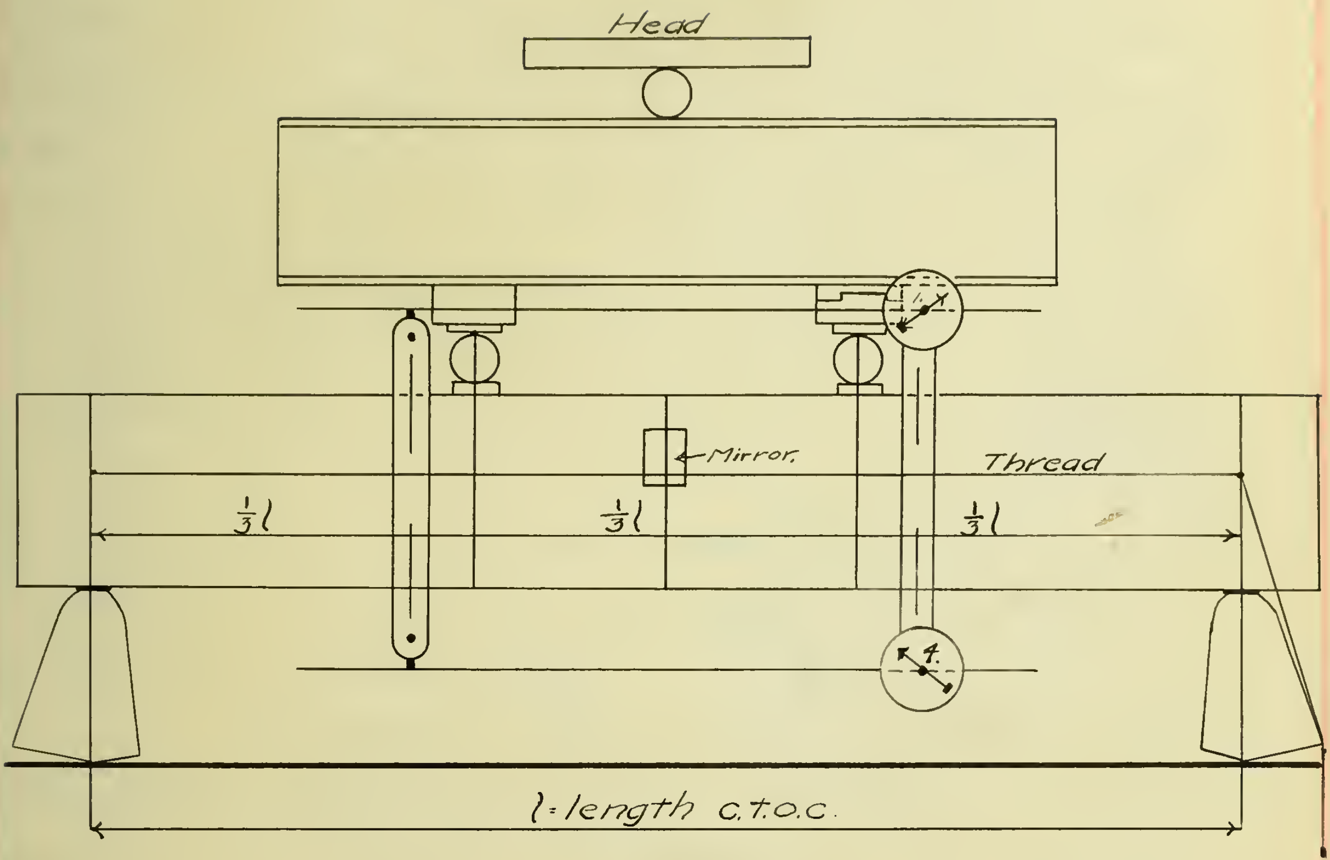


PLATE III.

Diagram showing position of Beam in Machine.

Showing position of Extensometers and

method of taking deflection.

IV EXPERIMENTAL DATA AND DISCUSSION.

Explanation of Tables. The general data on the manufacture of the fifty beams which were tested, is found in Table 7. The columns headed "Kinds of Concrete" give the pro ortions by volume of the mixture from which each test beam was made. The proportion of the mixture by weight is found in Table 6. In Tables 8, 9, 10, 11, 12 and 13, the columns headed "Maximum Applied Load in Pounds" do not include the weight of the beam nor the loading apparatus. In determining the amount of vertical shear, the weight of the beam and loading apparatus was considered, 6 lb. per sq. in. being added to the unit-stress for a 6ft. beam, seven for an 8-ft. beam, 8 for a 10-ft. beam and 10 lb. per sq. in. for a 12-ft. beam. In obtaining the bond stresses the weight of the beam and loading apparatus was taken into account directly.

For convenience the beams have been divided into three classes. Under Class A come the beams without stirrups, made from various mixtures of concrete and containing different reinforcements. The test span for the beams of this class was 6 ft. The beams of Class B were all of 1-2-4 mixture and the test spans varied from 8 to 12 ft. No stirrups were used. The beams of class C, which were of 1-2-4 concrete, contained vertical U stirrups and varying percentages of longitudinal reinforcement. The test span for beams of this class was 6 ft. The longitudinal reinforcement in all the beams consisted of straight mild steel round rods or high steel corrugated bars.

Comparisons The comparisons to be made between the beams of Class A are the effect, (a) of the quality of concrete,

(b) of the variations of age and (c) of the variation of reinforcement upon the beams in resisting web stresses. The beams of Class B will be compared with each other and with those of Class A, to see what effect the variation in length has upon the beam to resist the web stresses. In discussing Class C the beams will be compared with those of Class A to ascertain the effect of vertical reinforcement and anchored ends in increasing the resistance to web stresses.

Curves and Method of Plotting For each beam a curve was plotted using the applied load in pounds as ordinates and deflection at the center in inches as abscissae. For beams with spans of 8, 10 and 12 ft. the true deformations and the positions of the neutral axis were determined graphically from the extensometer readings, and were plotted with reference to the corresponding applied loads in pounds. Fig. 1 shows the graphical method of obtaining these values.

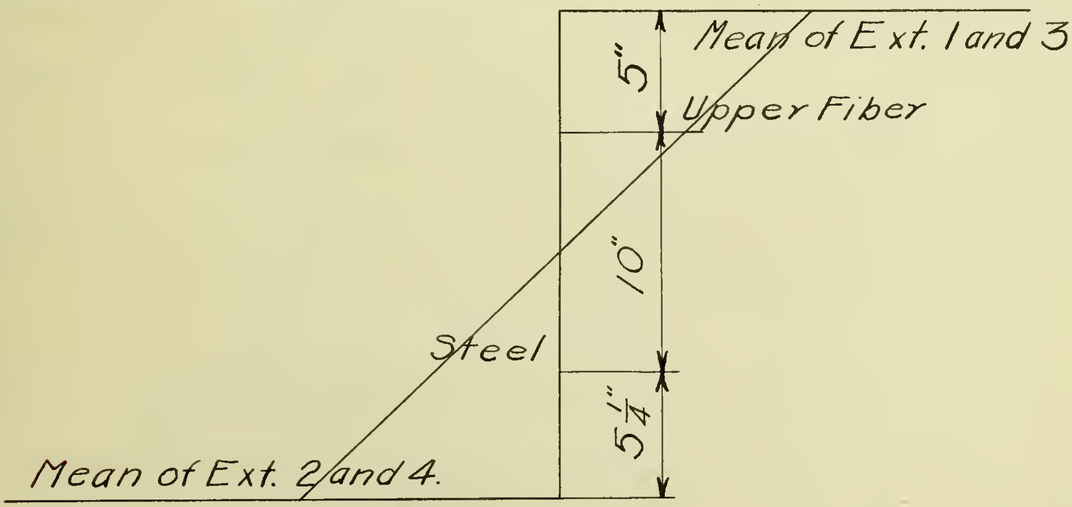


Fig. 1.

The mean reading of two upper dials was laid off horizontally to scale in one direction and the mean reading of the two lower dials was laid off to scale in the other

direction. A line connecting these two points intersects the vertical line at a point which represents the position of the neutral axis, and any horizontal intercept within the beam represents the deformation of the corresponding fiber. The unit deformation in the upper fiber and the steel were obtained by dividing the deformations thus obtained by the gage length of the extensometer.

Class A.

Effect of Quality of Concrete. The purpose of this discussion is to determine the effect of the quality of concrete upon the vertical shearing unit-strength of the beam. Tests were made on beams made of six mixtures as follows, 1-1-2; 1-1 1/2-3; 1-2-4; 1-3-6; 1-4-8; and 1-5-10. A curve was drawn using the ratio of the weight of the cement to the total weight of the mixture, and the vertical shearing unit-strength of the corresponding beams, as ordinates. All points on this curve were obtained from beams which failed by diagonal tension. (see page 43.)

The range of the values of the vertical shearing unit-strength maybe summarized as follows,

1-1-2 concrete - - 182 to 190 lb. per sq. in.
Average 186

1-1 1/2-3 concrete - 141 to 180 lb. per sq. in.
Average 161

1-2-4 concrete - 134 to 171 lb. per sq. in.
Average 152

1-3-6 concrete - 101 to 165 lb. per sq. in.
Average 133

1-4-8 concrete - 101 to 110 lb. per sq. in.
Average 105

1-5-10 concrete - 70 to 78 lb. per sq. in
Average 75

All of the beams representing the above mixtures, used in this comparison, were tested at the age of from 60 to 73 days andwere reinforced with 0.98 per cent of mild steel plain round rods. The test span was 6 ft. in each case. In all beams of this class with the exception of three, the failure was by diagonal tension, the three exceptions being by tension in the steel. In the beams with a low percentage of cement the fialure was in gneral quite sudden, the first crack not appearing until over 90 per cent of the ultimate load had been applied; and in many cases no cracks appeared until the beam failed. For the beams of a rich mixture of concrete, the cracks generally appeared when about 75 per cent of the ultimate load had been applied. The cracks opened quite slowly until the ultimate load had been reached and then in most cases split suddenly toward the end of the beam above the longitudinal reinforcement. A characterisitic failure is shown on Plate IV.

Effect of age A curve was drawn shown on page 44 to represent the variation of the vertical shearing unit-strength with the increase in age. The concrete was approximately 1-2-4 mixture and the reinforcement was 0.98 per cent plain round mild steel rods. The test span was 6 ft. The failures in all cases were by diagonal tension. As seen from the curve the results have a wide variation. However the curve shows that the vertical shearing unit-strength increases quite rapidly with the age. Increase in the age of the beam has the same effect on the time of appearance of the first crack , as has the increase in percentage of cement. For beams 217.0 and 217.1 the ages of which were 14 and 15 days respectively, the first crack appeared at 95 and 96 per cent of the ultimate load. For beam 217.4 whose age was 81 days, the first crack appeared at 65 per cent of the ultimate load.

Effedt of Percentage of Reinforcement. A curve was drawn (see page 45) to show what effect the percentage of reinforcement has on the vertical shearing unit-strength of the concrete. All values plotted were obtained from beams of 6 ft. span, and of the same mixture and age, and which had failed by diagonal tension. The curve shows that vertical shearing unit-strength has a decided increase with the increase of the percentage of reinforcement. This may be explained by the fact that, with the increase in the percentage of steel, the deflection of the beam is not so great and hence the elongation of the steel and concrete is decreased. This reduces the tension in the concrete, thus reducing the horizontal component of the diagonal tension.

Hence it is seen that the diagonal tensile unit-stress is not proportional to the vertical shearing unit-stress unless the stiffness of the beams under consideration is constant. If for a constant cross section and mixture of concrete, it is desired to compare the beams of varying lengths, or if the length also being constant, it is desired to compare the effect of different methods of web reinforcement, it is possible to do this if a correction is applied for the variation in percentage of reinforcement. This correction, for a beam of 6 ft. span, and 8-in. by 11 in. cross section, may be obtained from the curve on page 46. It is suggested that all vertical shearing unit-stresses be reduced to those corresponding to a 1.0 per cent reinforcement.

Class B.

Effect of Length. The beams discussed here were all of 1-2-4 mixture and were about 60 days old. The 6 ft. beams, which for convenience have been included under Class A in the tables, contained 0.98 per cent reinforcement, while the 8 ft., 10 ft. and 12 ft. beams of Class B, contain respectively 1.23, 1.70 and 2.21 per cent of reinforcement. Failure occurred in each case by diagonal tension, the first crack appearing at a load of about 70 per cent of the ultimate load. The crack, by which the various beams failed, generally appeared first just above the longitudinal reinforcement and at a distance approximately half way between the load point and the end of the beam. The crack gradually extended upward toward the load point as the deflection increased,

extended longitudinally along the top of the reinforcing bars.

A curve was drawn (see page 46) to show the effect of the length of the beam has upon the vertical shearing unit-stress. All the values plotted were obtained from beams of 1-2-4 concrete which failed by diagonal tension. However the percentage of reinforcement was not the same, but to insure the beams failing by diagonal tension, varied from, 0.98 mild steel for the 6-ft. beams, 1.23 per cent for the 8-ft. beams, 1.70 per cent for the 10-ft. beams to 2.21 per cent for the 12-ft. beams. This is an increase of about 1.25 per cent reinforcement, and referring to the curve it is seen that this increase in percentage should give an increase in strength above that of 0.98 per cent, of 12 lb. for 1.23 per cent reinforcement of 25 lb. for 1.70 per cent and 40 lb. for 2.21 per cent. Correcting the length-vertical-shear curve for this increase in percentage of reinforcement, it is seen thatthe vertical shearing unit-strength falls off rapidly with the increase in length of the beam.

Class C.

Effect of the Addition of Stirrups. The characteristic difference between beams of this class and those of Class A is the use of vertical stirrups, With the exception of one beam, all failures secured by diagonal tension, one failing by tension in the steel. The use of stirrups does not seem to have had any influence in the time of the appearance of the first crack. However, instead of failing suddenly as did the beams of Class A, these failed more gradually, and the stirrups, having begun to take the vertical component of the stress when the crack first appeared, prolonged the life of the beams considerably.

From the curve on page 45 the vertical shearing-strength for the beams of 1-2-4 mixture and 1.23 plain round mild steel reinforcement is 163 lb. per sq. in., for 1.66 per cent it is 175 lb. per sq. in. and from the value in Table 9 the vertical shearing-strength for 1.25 per cent corrugated high steel bars is 173 lb.per sq. in. Comparing these values with the average of those for Class C, with the same amount of reinforcement but with vertical stirrups: for 1.23 per cent plain reinforcement, the average value of the vertical shearing strength is 189 lb. per sq. in. an increase of 15.9 per cent, 1.66 per cent of the plain reinforcement it is 198 lb. per sq. in. an increase of 13.1 per cent, and for 1.25 per cent of the corrugated high steel bars it is 207 lb. per sq. in. an increase of 19.7 per cent. This shows that there is a decided increase in a vertical shearing strength

with the additon of stirrups, particularly with corrugated longitudinal reinforcement.

Effect of Anchored Ends. Beam 240.2 of Class A and Beam 240.1 of Class C. were each reinforced with 1.66 per cent of plain round steel rods and the ends of each were anchored with nuts and washers, the latter however being reforced vertically with 1/2-in. round stirrups spaced 5-in. apart. The maximum applied load on 240.2 was 20500 lb. giving a vertical shearing unit-strength of 153 lb. which is even less than what a similar beam without the anchored ends should carry.

While results of this one test may prove nothing, yet it points to the conclusion that anchoring of the ends of the longitudinal bars in a beam without stirrups does not increase its strength. Only in cases where slipping of the bar would otherwise occur would it be supposed that anchoring the ends would be of any benefit. The maximum applied load on Beam 240.1 was 34800 lb. this giving a vertical shearing unit-strength of something more than 256 lb., for the full shearing strength was not developed because failure came by tension in the longitudinal reinforcement. Comparing this value with the average vertical shearing stress for Beams 221.3 and 221.4, like 240.1 except thatthe reinforcement did not have anchored ends, it is seen how greatly the anchored ends add to the strength of beams with stirrups. This would point to the conclusion t hat slipping of the bars had something to do with the failure of th some of the beams in this class. Another thing which points to this conclusion

is the fact that the beams with corrugated bars show an increase in strength of 19.7 per cent with the addition os stirrups while the beams with plain round bars only show an increase in strength of about 14 or 15 per cent with the addition of stirrups.

Failure by Slipping Although in several cases there was slipping of the stirrups, yet in only one case did this occur at a load of more than 100 or 200 lb. under the maximum load. The exception mentioned was Beam 243.3 in which one leg of the stirrup showed signs of slipping at a load of 27000 lb., although the other leg did not slip until failure occured at 34200 lb. This first slip was probably caused by a short vertical crack that had opened at that point.

The explanation advanced for the failure of all of the beams with stirrups, except Beam 240.1 which, as has been said failed by tension in the steel is as follows; the primary cause of the failure was the partial slipping of the longitudinal reinforcement in the outer third of the beam. Because of this the concrete was required to take more of the tension and this increase in tension, in combination with the vertical shearing stress already present outside of the load point caused a diagonal tension crack to open. This gave the beams the appearance of having failed primarily by diagonal tension.

Size and Spacing of Stirrups From the examination of Table 10 it seems that the size and the spacing of the stirrups has no effect upon the time of appearance of the first

crack, the manner of failure, or the ultimate load.

<u>Specials.</u> Beam 522.1 of Class C was the only one tested which contained imitation Kahn reinforcement. The arrangement of the reinforcement is shown in Plate VII. The beam failed under an ultimate load of 24500 lb., which shows that about the same strength was developed in this beam as in those of Class A having the same mixture. This method of reinforcement does not show as high an efficiency as the method in which vertical stirrups are used.

Beam 229.1 contained 5 1/2 - in. vertical stirrups spaced 5 in. apart at one end only, the total load being applied directly at the one-third point,and deflections were read at the center and the third points. Curves between the applied loads and these deflections are shown on page 72. The beam failed by diagonal tension at an ultimate load of 20200 lb. The method of loading seems to have had no effect on the time of appearance of the first crack or on the manner of failure.

Summary   From the above discussions, the following conclusions have been reached:--

(1) The quality of the concrete and the age of a beam are important factors in fixing its diagonal tensile strength.

(2) The manner of failure of a beam by diagonal tension whether slowly of suddenly, depends largely upon the quality of its concrete and its age. For a 60-day beam of 1-5-10 mixture or a 15 day beam of 1-2-4 mixture, the first crack appears at 90 to 100 percent of the ultimate load, while for a 60-day beam of a 1-1-2 or 1-2-4 mixture the first crack appears at about 70 percent of the ultimate load, and the beam fails more gradually.

(3) The diagonal tensile strength of a beam as measured by the vertical shearing stress developed increases with the stiffness produced by a higher percentage of reinforcement.

(4) With the decrease in stiffness accompanying an increased length of a beam, the diagonal tensile strength measured by the vertical shearing stress developed, decreases as the length of the beam increases.

(5) The diagonal tensile strength developed in a beam with stirrups is higher than that developed in a beam without web reinforcement. Beams with web reinforcement are less liable to sudden and total failure than are those without web reinforcement. This is due to the fact that the stress, which causes the sudden opening of the crack and the

failure of the beam with only longitudinal reinforcement, is carried by the web reinforcement until a higher ultimate load is finally reached.

(6) Without stirrups, beams with anchored longitudinal reinforcement or corrugated bars developed no higher diagonal tensile stength than beams with plain reinforcement only. Beams with stirrups and corrugated longitudinal bars, and especially beams with stirrups and anchored longitudinal reinforcement, develop a considerably higher diagonal tensile strength than those with plain vertical and longitudinal reinforcement. This shows that the addition of stirrups enables the beams to carry an additional load which increases the bond stress in the longitudinal reinforcement to such an extent that, unless deformed bars are used, or the ends of of the plain rods are anchored, failure will be caused primarily by the slipping of the longitudinal reinforcement.

(7) It follows from the above discussion that the best method of resisting web stresses is by the use of web reinforcement in addition to the longitudinal reinforcement. Of the methods testes, the best in order of their efficiencies are, (a) stirrups with anchored longitudinal reinforcement, (b) The use of stirrups with corrugated longitudinal bars, and (c) the use of stirrups with plain rods for longitudina reinforcement. In any of these cases, the ability to resist web stresses is increased by using a richer mixture, or a higher percentage of longitudinal reinforcement.

TABLE 8.

Experimental Data on Beam Test.

Class A.

Beam	Age in Days	Load at First Crack lb.	Maximum Applied Load lb.	Manner of Failure.
218.1	64	19000	24900	Tension in Steel
218.2	67	19000	23000	Diagonal Tension
218.3	46	13000	16600	Diagonal Tension
218.4	61	17000	17300	Diagonal Tension
219.1	65	25000	25200	Diagonal Tension
219.2	67	14000	21700	Diagonal Tension
220.1	68	23900	23900	Diagonal Tension
220.2	66	27000	27000	Diagonal Tension
220.5	36	17000	19400	Diagonal Tension
217.0	14	15400	16200	Diagonal Tension
217.1	15	13500	14000	Diagonal Tension
217.2	63	20000	20000	Diagonal Tension
217.3	32	17900	18500	Diagonal Tension
217.4	81	16000	24700	Tension in Steel
217.5	36	13000	13600	Diagonal Tension
252.5	66	25000	26000	Diagonal Tension
252.6	66	20000	20800	Diagonal Tension
252.7	64	19000	23700	Diagonal Tension
210.1	63	21000	25600	Diagonal Tension
210.2	72	18000	31000	Tension in Steel
210.3	60	19000	24500	Diagonal Tension
211.4	63	16000	18800	Diagonal Tension
211.5	72	15900	24200	Diagonal Tension
213.3	68	16000	22200	Diagonal Tension
213.4	67	9000	13300	Diagonal Tension
2.14.3	67	14500	14500	Diagonal Tension
214.4	73	12000	13200	Diagonal Tension
214.5	64	12000	13800	Diagonal Tension
215.3	67	9700	9700	Diagonal Tension
215.4	71	9700	10000	Diagonal Tension
215.5	67	8900	8900	Diagonal Tension
240.2	64	18000	20500	Diagonal Tension

TABLE 9.

Experimental Data on Beam Tests.

Class B.

Beam No.	Age in Days	Load at first Crack lb.	Maximum Applied Load lb.	Manner of Failure.
256.1	64	13000	18200	Diagonal Tension
256.2	71	13000	21000	Diagonal Tension
255.1	63	13000	18900	Diagonal Tension
255.2	63	14000	20000	Diagonal Tension
254.1	63	12000	16700	Diagonal Tension
254.2	75	15000	22200	Diagonal Tension
253.1	67	20000	21300	Diagonal Tension
253.5	66	11000	18500	Diagonal Tension
253.6	64	24500	24500	Diagonal Tension

TABLE 10.

Experimental Data on Beam Tests.
Class C.

Beam No.	Age in Days	Load at first crack lb.	Maximum Applied Load lb.	Manner of failure
221.3	57	24000	31100	Diagonal Tension
221.4	70	20000	21200	Diagonal Tension
223.2	57	22000	24600	Diagonal Tension
223.3	70	20000	26200	Diagonal Tension
240.1	60	26000	34800	Tension in concrete –
243.3	64	20000	34200	Diagonal Tension
243.4	64	18000	21600	Diagonal Tension
Loaded at one 1/3-point				
229.1	63	20000	22000	Diagonal Tension
Special Kahn reinforcement.				
5 222.1	60	18200	24500	Diagonal Tension

TABLE 11.

Computed Data on Beams.

Class A.

Beam No.	Age in Days	Per cent Steel	Mixture	Max. Applied Load lb.	Calculated Stresses Steel	Concrete	Shear	Bond
218.1	64	0.98	1-2-4	24900	43800	1840	185	235
218.2	67	0.98	1-2-4	23000	40400	1700	171	217
218.3	46	0.98	1-2-4	16600	29200	1230	125	159
218.4	61	0.98	1-2-4	17300	30400	1280	130	165
219.1	65	1.46	1-2-4	25200	29500	1870	178	159
219.2	67	1.46	1-2-4	21700	25400	1610	162	138
220.1	68	2.21	1-2-4	23900	18600	1770	177	151
220.2	66	2.21	1-2-4	2700	21100	2000	200	170
220.5	36	1.96	1-2-4	19400	17000	1390	148	185
217.5	36	0.98	1-2-4	13600	23900	1010	107	131
217.0	14	0.98	1-2-4	16200	28500	1200	122	155
217.1	15	0.98	1-2-4	1400	24600	1040	107	135
217.2	63	0.98	1-2-4	20000	35200	1480	151	190
217.3	32	0.98	1-2-4	18500	32500	1370	139	176
217.4	81	0.98	1-2-4	24700	43400	1830	183	233
252.7	64	1.25	1-2-4	23700	32700	1760	176	176
252.6	66	1.25	1-2-4	20800	28700	1540	156	156
252.5	66	1.25	1-2-4	26000	35900	1930	186	192
210.1	63	0.98	1-1-2	25600	45000	1900	190	241
210.2	72	0.98	1-1-2	31000	54400	2300	229	302
210.3	60	0.98	1-1-2	24500	43000	1820	182	231
211.4	63	0.98	1-1 1/2-3	18800	33000	1390	141	178
211.5	72	0.98	1-1 1/2-3	24200	42500	1790	180	228
213.3	68	0.98	1-3-6	22200	38900	1640	165	210
213.4	67	0.98	1-3-6	13300	23400	980	101	129
214.3	67	0.98	1-4-8	14500	25400	1070	110	140
214.4	73	0.98	1-4-8	13200	23200	980	101	127
214.5	64	0.98	1-4-8	13800	24200	1020	105	134
215.3	67	0.98	1-5-10	9700	17000	720	76	96
215.4	71	0.98	1-5-10	10000	17600	740	78	99
215.5	67	0.98	1-5-10	8900	15600	660	70	88
x240.2	64	1.66	1-2-4	20500	21400	1520	153	174

x Longitudinal rods anchored at ends with nuts and washers.

TABLE 12.

Computed Data on Beams.

Class B.

Beam No.	Span	Percent Steel Reinforcement	Max. Load in Pounds	d' in Inches	Stress in Steel From Mom.	Stress in Steel From Elongation	Stress in Concrete	Unit Shear $v=\frac{V}{bd'}$	Unit Bond Stress	Unit Elong. in Steel	K
256.1	12	2.21	18200	8.17	30200	31400	1970	149	127	.001045	.51
256.2	12	2.21	21000	8.20	34800	39400	2310	170	145	.001312	.50
255.1	10	1.67	18900	8.28	34200	30000	1790	151	171	.001000	.48
255.2	10	1.71	20000	8.20	35600	29100	1830	160	116	.000969	.50
254.1	8	1.23	16700	8.28	32900	24300	1260	133	135	.000810	.48
254.2	8	1.23	22200	8.52	42300	35400	1910	169	177	.001181	.41
□ 253.1	12	2.81	21300	7.99	28500	27800	2140	176	118	.000925	.56
□ 253.5	12	1.25	18500	8.38	53000	58200	2210	148	148	.001939	.45
× 253.6	6	1.25	24500	8.70	33800	——	1820	186	182	——	—

$d' = d - .36kd$

$E = 30000000$

Stress in steel from elongation $S = Es.$

□ High Steel corrugated bars.

× The extensometer was not used on this beam; d' was assumed.

TABLE 13.

Computed Data on Beams.

Class C.

Span 6 ft. Mixture 1-2-4.

Beam No.	Age in Days	Reinforcement per cent steel		Maximum Load lb. per sq. in.	Unit-Stresses			
					Steel	Concrete	Vert.	Bond Hor. Reinf.
221.3	57	1.66	plain round	31100	32400	2300	230	259
□221.4	70	1.66	plain round	21200	22100	1570	158	177
223.2	57	1.23	plain round	24600	34500	1820	183	186
223.3	70	1.23	plain round	26200	36800	1940	194	197
240.1	64	1.66	anchored	34800	36200	2580	256	289
243.3	64	1.25	cor. h. s.	34200	47200	2530	252	252
243.4	64	1.25	cor. h. s.	21600	29800	1600	161	161
522.1	60	1.25	Im. Kahn	24500	33800	1810	182	145
x229.1	63	1.23	plain round	22000	30900	1630	164	167

□ poor concrete see Table 6.

x Loaded at one 1/3-point only.

B E A M 256.1

Loaded at 1/3 points
4 3/4 in. plain round rods

Concrete 1:2:4.
Gage length 40 in.

Applied Load Lbs.	Center Deflec tions	Extensometer Readings-inches I	II	III	IV	Unit Deformation Upper Fiber	Steel	K
1000	.02	.0029	.0023	.0031	.0029	.000040	.000027	.59
2000	.03	.0053	.0042	.0055	.0051	.000072	.000050	.60
3000	.05	.0090	.0073	.0094	.0083	.000127	.000080	.61
4000	.07	.0128	.0104	.0130	.0114	.000177	.000112	.61
5000	.08	.0158	.0128	.0616	.0144	.000222	.000137	.62
6000	.10	.0198	.0166	.0191	.0181	.000272	.000180	.60
7000	.13	.0247	.0216	.0249	.0271	.000335	.000245	.58
8000	.16	.0300	.0271	.0304	.0288	.000402	.000312	.56
9000	.18	.0351	.0327	.0455	.0342	.000467	.000377	.55
10000	.21	.0407	.0382	.0413	.0400	.000540	.000442	.55
11000	.24	.0460	.0434	.0468	.0454	.000612	.000502	.55
12000	.28	.0521	.0496	.0532	.0516	.000661	.000572	.55
13000	.31	.0581	.0554	.0594	.0574	.000769	.000635	.55
14000	.35	.0654	.0619	.0662	.0642	.000860	.000717	.54
15000	.39	.0714	.0674	.0678	.0698	.000892	.000792	.53
16000	.42	.0787	.0737	.0719	.0764	.000964	.000875	.53
17000	.47	.0863	.0802	.0726	.0831	.001007	.000960	.51
18000	.51	.0946	.0871	.0733	.0883	.001050	.001045	.52
18210	Maximum Load							

B E A M 256.2

Loaded at 1/3 points
4 3/4 in. plain round rods.

Concrete 1:2:4.
Gage length 40 in.

Applied Load Lbs.	Center Deflections	Extensometer Readings-inches I	II	III	IV	Unit Deformation Upper Fiber	Steel	K
1000	.01	.0024	.0022	.0031	.0026	.000040	.000025	.58
2000	.03	.0053	.0046	.0054	.0056	.000075	.000055	.57
3000	.05	.0086	.0076	.0092	.0087	.000118	.000088	.57
4000	.065	.0127	.0114	.0133	.0130	.000182	.000127	.58
5000	.085	.0171	.0157	.0178	.0178	.000228	.000188	.55
6000	.09	.0214	.0201	.0224	.0227	.000282	.000248	.54
7000	.13	.0262	.0252	.0274	.0282	.000372	.000310	.53
8000	.165	.0316	.0315	.0332	.0347	.000417	.000387	.52
9000	.19	.0369	.0374	.0391	.0413	.000480	.000467	.51
10000	.23	.0427	.0440	.0452	.0481	.000554	.000547	.51
11000	.25	.0478	.0495	.0507	.0541	.000620	.000615	.51
12000	.285	.0532	.0553	.0563	.0603	.000687	.000690	.50
13000	.315	.0590	.0614	.0615	.0668	.000760	.000755	.50
14000	.345	.0645	.0671	.0666	.0731	.000810	.000845	.49
15000	.380	.0705	.0732	.0724	.0796	.000887	.000920	.49
16000	.41	.0765	.0792	.0786	.0859	.000962	.000985	.50
17000	.45	.0830	.0855	.0857	.0933	.001050	.001064	.50
18000	.48	.0906	.0919	.0935	.1009	.001150	.001142	.51
19000	.53	.0978	.0993	.1012	.1081	.001250	.001219	.51
20000	.57	.1049	.1061	.1088	.1166	.001325	.001312	.50
21000	Maximum Load							

B E A M 255.1

Loaded at 1/3 points
3 3/4 in. plain round rods

Concrete 1:2:4.
Gage length 32 in.

Applied Load Lbs.	Center Deflections	Extensometer Readings-inches I	II	III	IV	Unit Deformation Upper Fiber	Steel	K
1000	.005	.0018	.0024	.0025	.0017	.000035	.000029	.55
2000	.01	.0036	.0027	.0044	.0034	.000071	.000036	.66
3000	.02	.0057	.057	.0064	.0054	.000101	.000076	.58
4000	.03	.0076	.0063	.0084	.0073	.000136	.000089	.61
5000	.04	.0100	.0085	.0107	.0097	.000178	.000118	.60
6000	.06	.0129	.0116	.0149	.0128	.000238	.000163	.59
7000	.07	.0159	.0150	.0166	.0162	.000272	.000212	.55
8000	.09	.0192	.0193	.0197	.0199	.000319	.000282	.54
9000	.10	.0216	.0244	.0229	.0267	.000332	.000376	.45
10000	.12	.0250	.0293	.0255	0301	.000378	.000463	.45
11000	.14	.0289	.0325	.0295	0339	.000448	.000513	.46
12000	.16	.0329	.0366	.0326	.0381	.000494	.000582	.46
13000	.19	.0368	.0409	.0364	.0423	.000556	.000648	.46
14000	.21	.0408	.0450	.0404	.0463	.000616	.000704	.47
15000	.23	.0446	.0498	.0442	.0506	.000675	.000772	.47
16000	.25	.0485	.0539	.0481	.0547	.000732	.000838	.47
17000	.27	.0527	.0583	.0522	.0591	.000810	.000905	.47
18000	.29	.0564	.0624	.0561	.0627	.000858	.000930	.47
18900	.36	.0593	.0652	.0590	.0652	.000910	.00100	.48
16410	Maximum Load							

B E A M 255.2

Loaded at 1/3 points
7 1/2 in. plain round rods

Concrete 1:2:4.
Gage length 32 in.

Applied Load Lbs.	Center Deflections	Extensometer Readings-inches I	II	III	IV	Unit Deformation Upper Fiber	Steel	K
1000	.005	.0014	.0014	.0018	.0017	.000026	.000021	.56
2000	.015	.0034	.0027	.0037	.0035	.000058	.000042	.59
3000	.025	.0053	.0042	.0057	.0053	.000063	.000062	.61
4000	.035	.0074	.0059	.0081	.0074	.000131	.000087	.60
5000	.045	.0096	.0078	.0104	.0094	.000170	.000113	.60
6000	.055	.0120	.0105	.0132	.0121	.000212	.000181	.59
7000	.07	.0148	.0133	.0164	.0152	.000263	.000194	.57
8000	.085	.0180	.0178	.0195	.0186	.000303	.000263	.54
9000	.10	.0210	.0201	.0239	.0223	.000363	.000325	.53
10000	.15	.0241	.0236	.0264	.0260	.000383	.000362	.53
11000	.135	.0277	.0274	.0307	.0310	.000469	.000421	.53
12000	.155	.0313	.0313	.0347	.0354	.000534	.000460	.52
13000	.175	.0347	.0355	.0385	.0398	.000585	.000553	.52
14000	.195	.0384	.0403	.0428	.0447	.000644	.000631	.51
15000	.215	.0425	.0447	.0475	.0498	.000710	.000703	.51
16000	.235	.0464	.0489	.0524	.0546	.000781	.000763	.51
17000	.255	.0497	.0531	.0564	.0595	.000837	.000840	.50
18000	.275	.0531	.0566	.0605	.0640	.000888	.000903	.50
19000	.300	.0568	.0605	.0650	.0689	.000846	.000969	.50
20000	Maximum Load							

B E A M 254.1

Loaded at 1/3 points
5 1/2 in. round mild steel rods

Concrete 1:2:4.
Gage length 40 in .

Applied Load Lbs.	Center Deflec tions	Extensometer Readings-inches I	II	III	IV	Unit Deformation Upper Fiber	Steel	K
1000	.01	.00026	.0019	.0028	.0024	.000048	.000021	.65
2000	.02	.0049	.0036	.0049	.0040	.000068	.000039	.66
3000	.02	.0069	.0050	.0069	.0058	.000097	.000053	.65
4000	.03	.0087	.0070	.0094	.0082	.000124	.000079	.62
5000	.035	.0120	.0091	.0117	.0103	.000164	.000095	.63
6000	.04	.0154	.0128	.0147	.0137	.000205	.000140	.60
7000	.05	.0185	.0164	.0174	.0168	.000240	.000182	.57
8000	.06	.0223	.0209	.0209	.0210	.000280	.000240	.54
9000	.07	.0267	.0265	.0248	.0260	.000327	.000285	.52
10000	.08	.0321	.0329	.0294	.0321	.000390	.000385	.51
11000	.09	.0370	.0375	.0341	.0379	.000447	.000450	.50
12000	.10	.0418	.0433	.0384	.0434	.000497	.000520	.49
13000	.12	.0465	.0493	.0428	.0488	.000547	.000592	.48
14000	.13	.0518	.0544	.0474	.0548	.000607	.000666	.48
15000	.15	.0583	.0610	.0529	.0617	.000680	.000750	.48
16000	.16	.0624	.0660	.0568	.0660	.000730	.000810	.48
16740	Maximum Load							

B E A M 254.2

Loaded at 1/3 points.
5 1/2 in. plain round rods.

Concrete 1:2:4.
Gage length 40 in.

Applied Load Lbs.	Center Deflection	Extensometer Readings-inches I	II	III	IV	Unit Deformation Upper Fiber	Steel	K
1000	.015	.0015	.0007	.0015	.0014	.000023	.000008	.74
2000	.02	.0034	.0023	.0032	.0032	.000047	.000027	.63
3000	.025	.0061	.0047	.0055	.0054	.000080	.000052	.60
4000	.0271	.0071	.0064	.0071	.0068	.000095	.000073	.56
5000	.035	.0104	.0091	.0095	.0094	.000130	.000103	.56
6000	.04	.0132	.0122	.0123	.0124	.000165	.000140	.54
7000	.045	.0155	.0145	.0145	.0145	.000197	.000163	.54
8000	.05	.0189	.0183	.0174	.0176	.000240	.000193	.53
9000	.06	.0219	.0224	.0202	.0214	.000265	.000260	.51
10000	.065	.0264	.0288	.0243	.0272	.000315	.000342	.49
11000	.085	.0319	.0365	.0284	.0341	.000372	.000425	.47
12000	.095	.0362	.0422	.0331	.0398	.000407	.000517	.44
13000	.110	.0414	.0492	.0380	.0469	.000460	.000613	.43
14000	.125	.0452	.0542	.0414	.0538	.000490	.000697	.42
15000	.135	.0497	.0598	.0454	.0574	.000550	.000737	.43
16000	.145	.0541	.0658	.0495	.0627	.000590	.000830	.42
17000	.165	.0587	.0673	.0541	.0686	.000652	.000865	.43
18000	.175	.0634	.0777	.0584	.0755	.000690	.000988	.41
19000	.185	.0671	.0821	.0618	.0590	.000730	.001043	.42
20000	.205	.0714	.0877	.0654	.0841	.000772	.001082	.41
21000	.215	.0759	.0929	.0693	.0892	.000815	.001181	.41
22000	Maximum Load							

B E A M 253.1

Loaded at 1/3 points
4 3/4 in. corrugated high steel bars

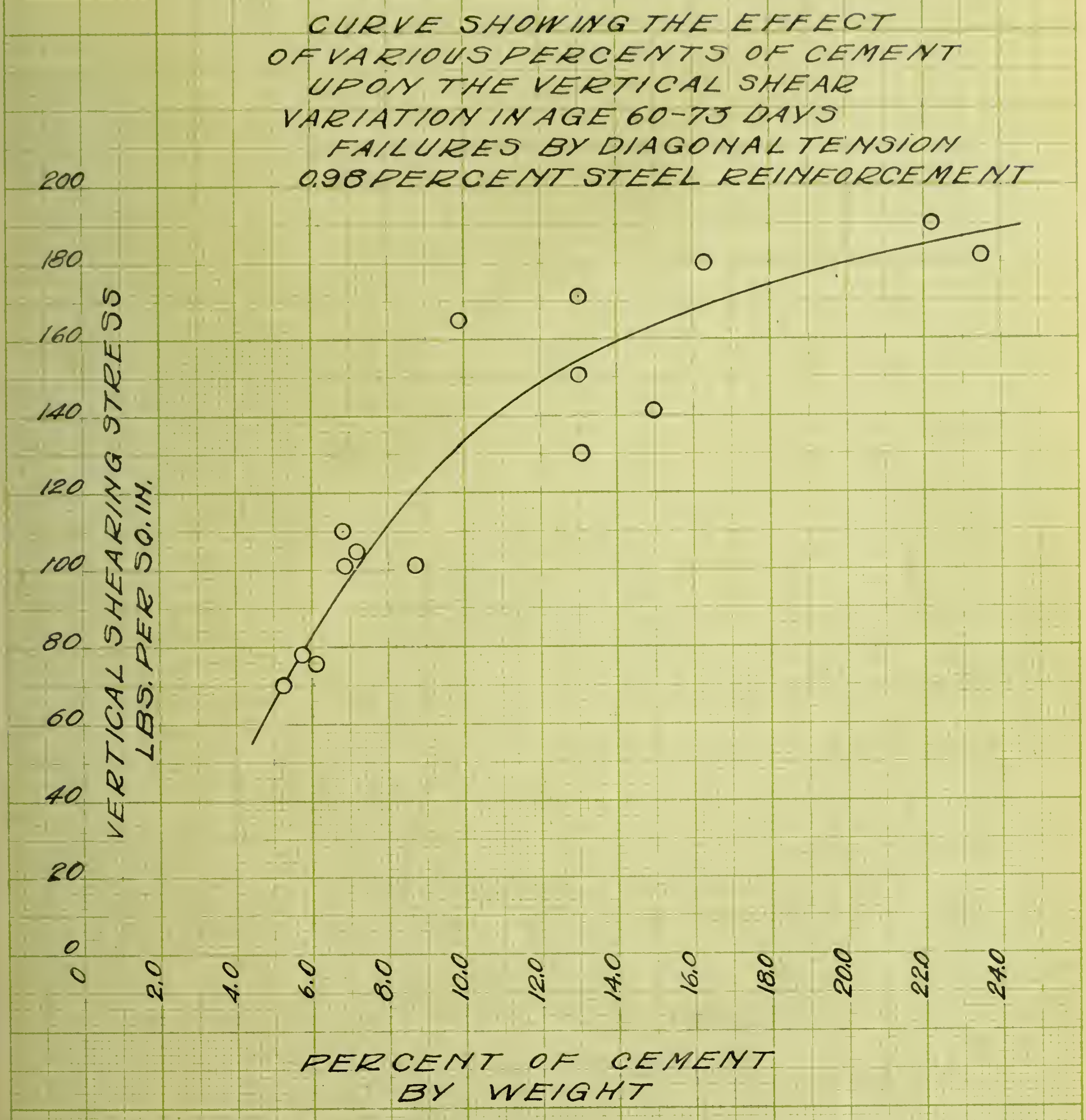
Concrete 1:2:4.
Gage length 40 in.

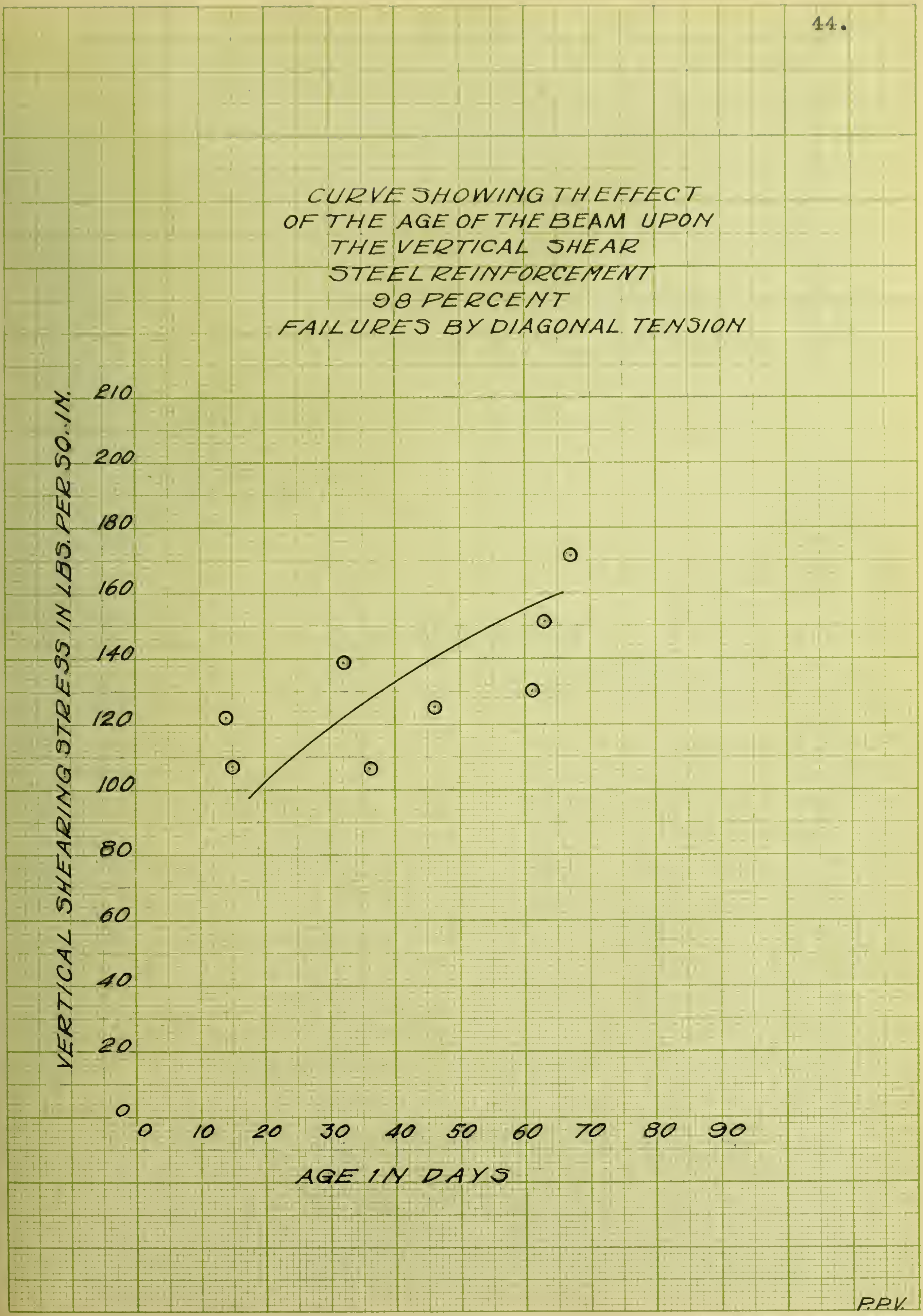
Applied Load Lbs.	Center Deflec tion	Extensometer Readings-inches				Unit Deformation		K
		I	II	III	IV	Upper Fiber	Steel	
1000	.01	.0024	.0015	.0032	.0016	.000045	.000008	.84
2000	.02	.0050	.0032	.0055	.0037	.000077	.000027	.74
3000	.03	.0079	.0053	.0083	.0059	.000120	.000047	.72
4000	.05	.0111	.0083	.0116	.0089	.000165	.000075	.68
5000	.06	.0144	.0112	.0147	.0117	.000205	.000107	.65
6000	.08	.0181	.0153	.0185	.0151	.000247	.000155	.62
7000	.10	.0218	.0188	.0221	.0185	.000302	.000192	.61
8000	.115	.0256	.0227	.0259	.0219	.000350	.000238	.60
9000	.14	.0300	.0273	.0302	.0262	.000412	.000285	.59
10000	.16	.0342	.0316	.0346	.0303	.000470	.000330	.59
11000	.19	.0383	.0360	.0390	.0344	.000517	.000385	.58
12000	.215	.0427	.0406	.0434	.0385	.000575	.000435	.57
13000	.23	.0470	.0452	.0382	.0429	.000635	.000487	.57
14000	.26	.0519	.0500	.0532	.0424	.000717	.000498	.57
15000	.29	.0564	.0552	.0581	.0520	.000758	.000592	.56
16000	.315	.0610	.0600	.0628	.0565	.00817	. 000650	.56
17000	.340	.0654	.0645	.0676	.0607	.000875	.000700	.56
18000	.37	.0707	.0699	.0729	.0656	.000930	.000762	.56
19000	.39	.0759	.0749	.0786	.0705	.001020	.000812	.56
20000	.43	.0181	.0803	.0848	.0759	.001096	.000867	.56
21000	.465	.0868	.0854	.0904	.0803	.001169	.000925	.56
21300	Maximum Load							

B E A M 253.5

Loaded at 1/3 points — Concrete 1:2:4.
4 1/2 in. corrugated high steel bars — Gage length 40in.

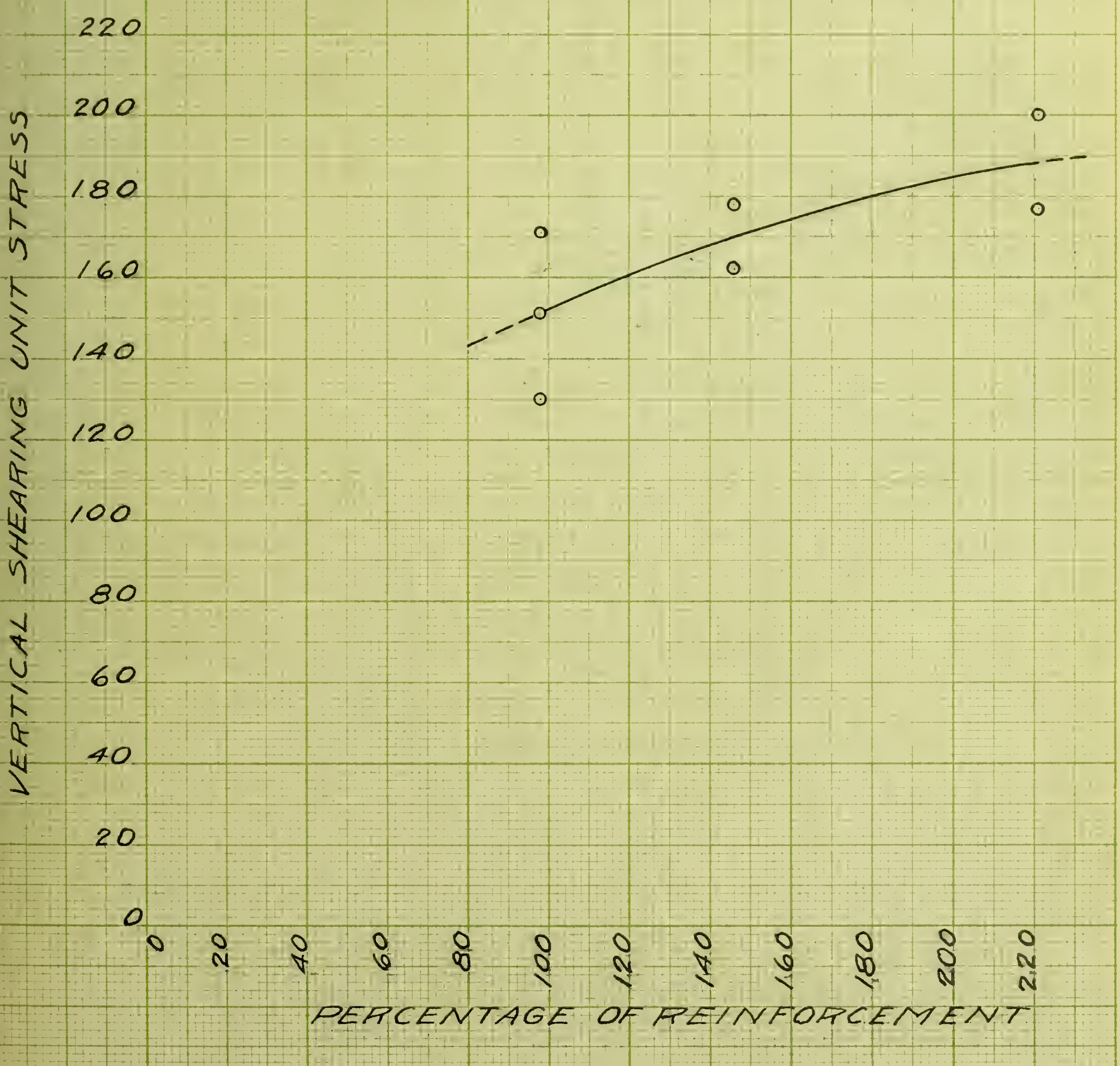
Applied Load Lbs.	Center Deflections	Extensometer Readings-inches I	II	III	IV	Unit Deformation Upper Fiber	Steel	K
1000	.015	.0028	.0022	.0027	.0026	.000037	.000025	.59
2000	.03	.0064	.0052	.0051	.0058	.000077	.000060	.57
3000	.06	.0110	.0099	.0108	.0104	.000150	.000110	.58
4000	.08	.0154	.0139	.0149	.0145	.000215	.000155	.58
5000	.10	.0199	.0187	.0195	.0191	.000267	.000208	.57
6000	.14	.0272	.0236	.0264	.0277	.000365	.000287	.56
7000	,18	.0342	.0307	.0332	.0364	.000455	.000378	.55
8000	.23	.0422	.0400	.0402	.0459	.000520	.000502	.53
9000	.30	.0499	.0488	.0470	.0537	.000633	.000600	.52
10000	.32	.0575	.0576	.0538	.0624	.000715	.000723	.50
11000	.37	.0660	.0657	.0609	.0708	.000820	.000813	.50
12000	.41	.0747	.0738	.0677	.0790	.000905	.000913	.50
13000	.47	.0817	.0820	.0745	.	.001000	.001020	.50
14000	.50	.0906	.0908	.0818	.0961	.001112	.001110	.50
15000	.55	.0988	.0995	.0891	.1047	.001189	.001212	.50
16000	.60	.1082	.1091	.0966	.1136	.001324	.001300	.50
17000	.65	.1183	.1191	.1040	.1221	.001475	.001400	.51
18000	.77	.1302	.1550	.1246	.1558	.001525	.001939	.45
18500	Maximum Load							


CURVE SHOWING THE EFFECT
OF VARIOUS PERCENTS OF CEMENT
UPON THE VERTICAL SHEAR
VARIATION IN AGE 60-73 DAYS
FAILURES BY DIAGONAL TENSION
0.98 PERCENT STEEL REINFORCEMENT
VERTICAL SHEARING STRESS
LBS. PER SQ. IN.
200
180
160
140
120
100
80
60
40
20
0
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
PERCENT OF CEMENT
BY WEIGHT
P.P.V.

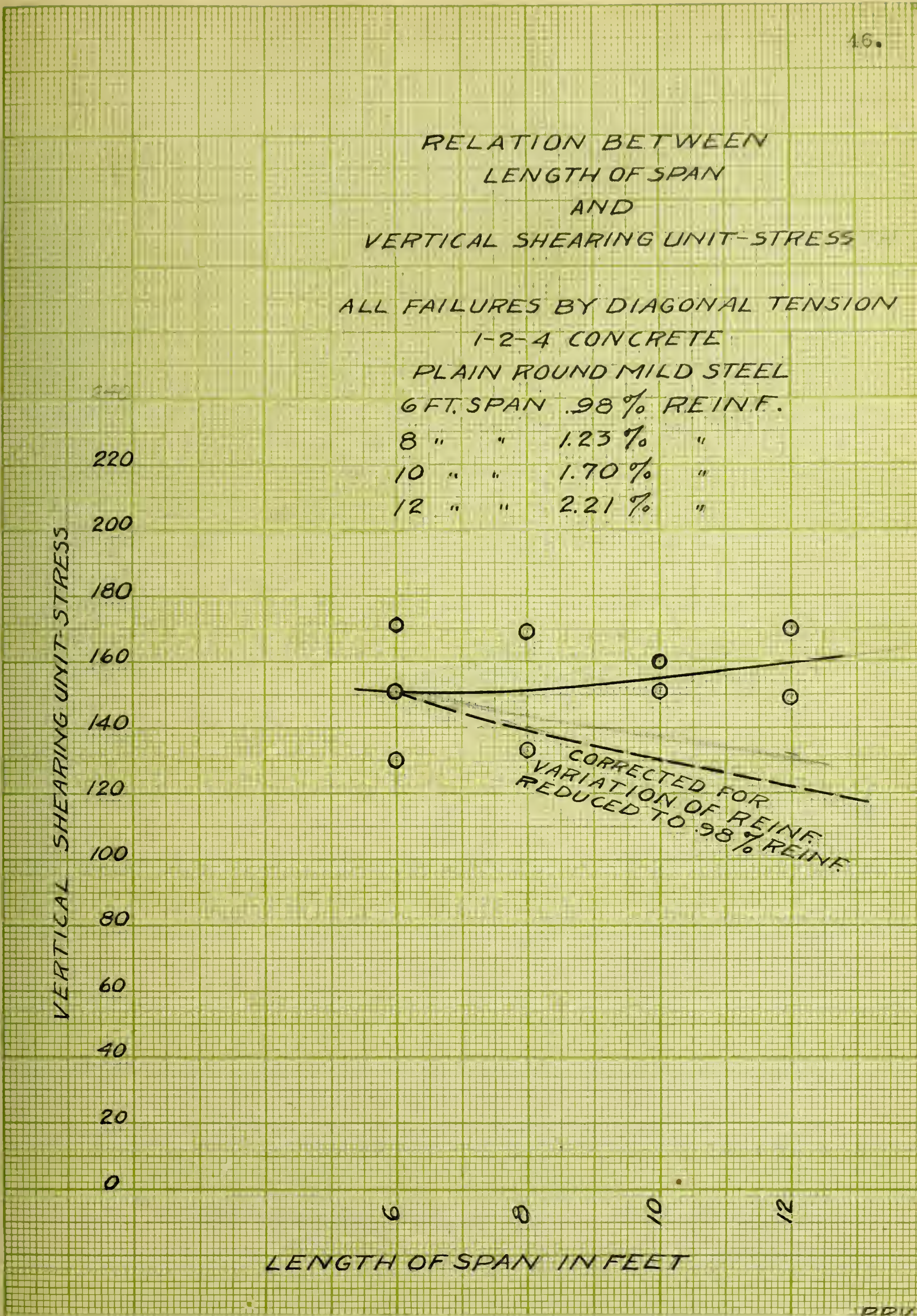

CURVE SHOWING THE EFFECT
OF THE AGE OF THE BEAM UPON
THE VERTICAL SHEAR
STEEL REINFORCEMENT
98 PERCENT
FAILURES BY DIAGONAL TENSION
VERTICAL SHEARING STRESS IN LBS. PER SQ. IN.
210
200
180
160
140
120
100
80
60
40
20
0
0 10 20 30 40 50 60 70 80 90
AGE IN DAYS
P.P.V.

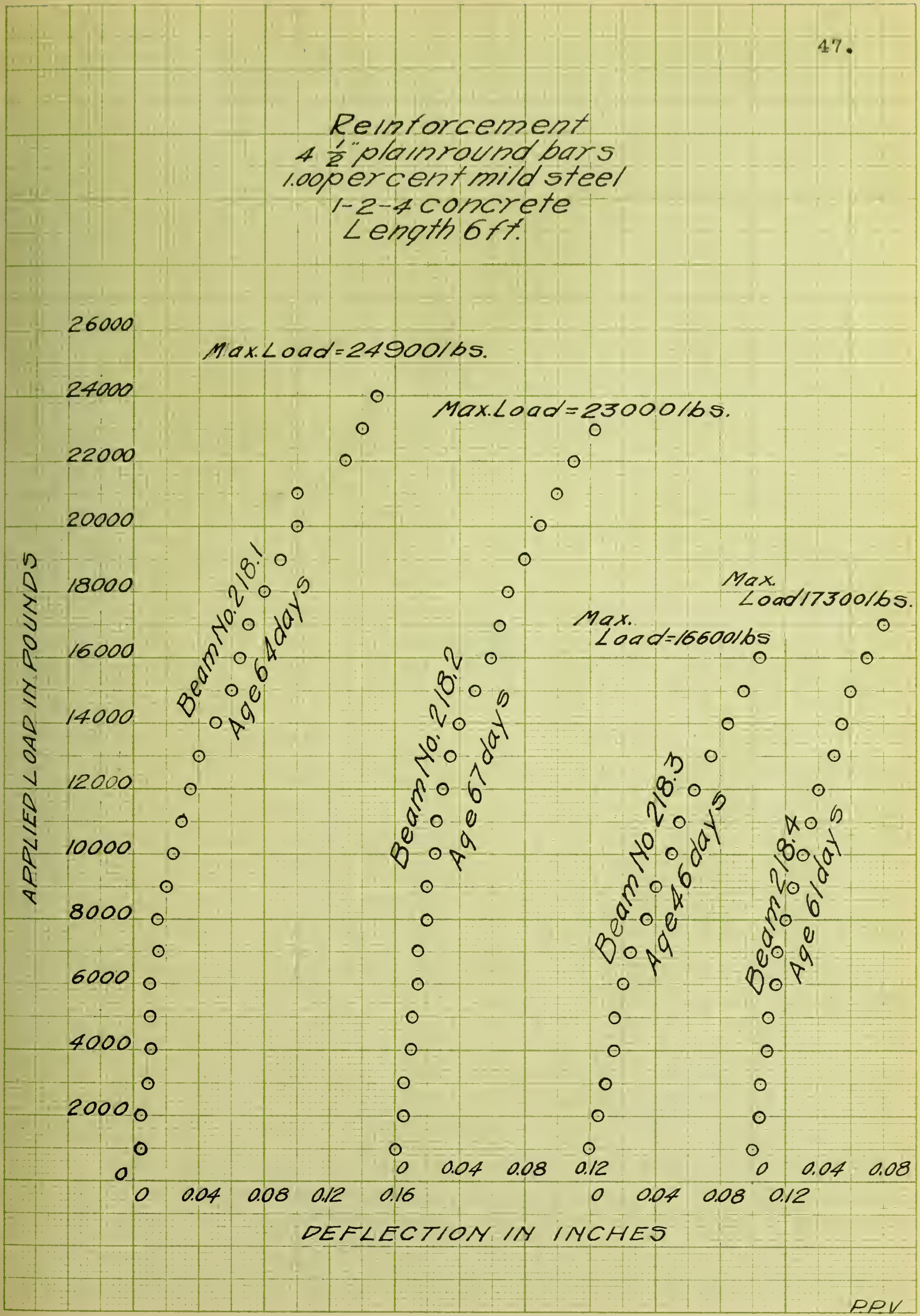
RELATION BETWEEN
PERCENTAGE OF REINFORCEMENT
AND
VERTICAL SHEARING UNIT STRESS

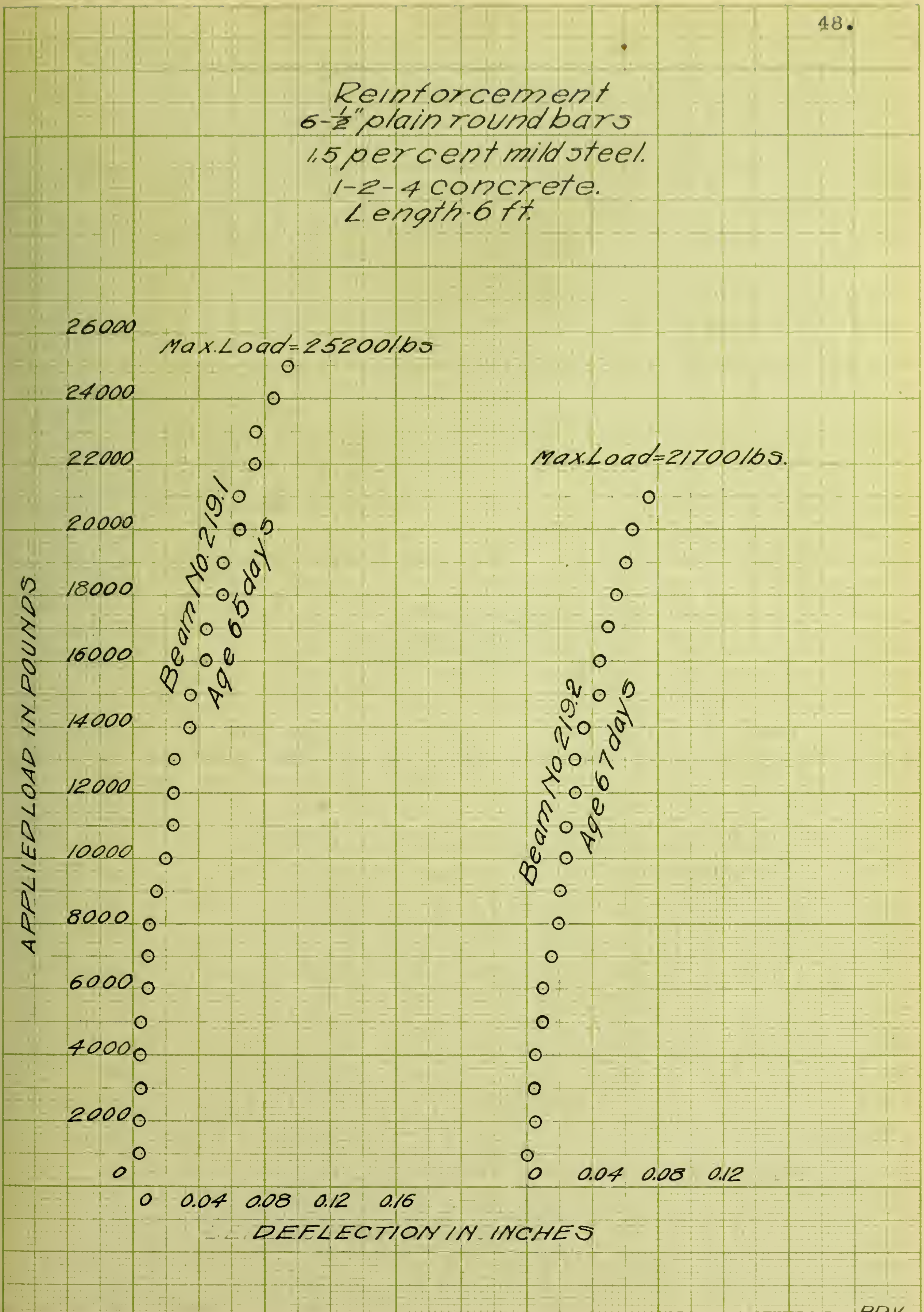
ALL FAILURES BY DIAGONAL TENSION
1-2-4 CONCRETE
PLAIN ROUND MILD STEEL

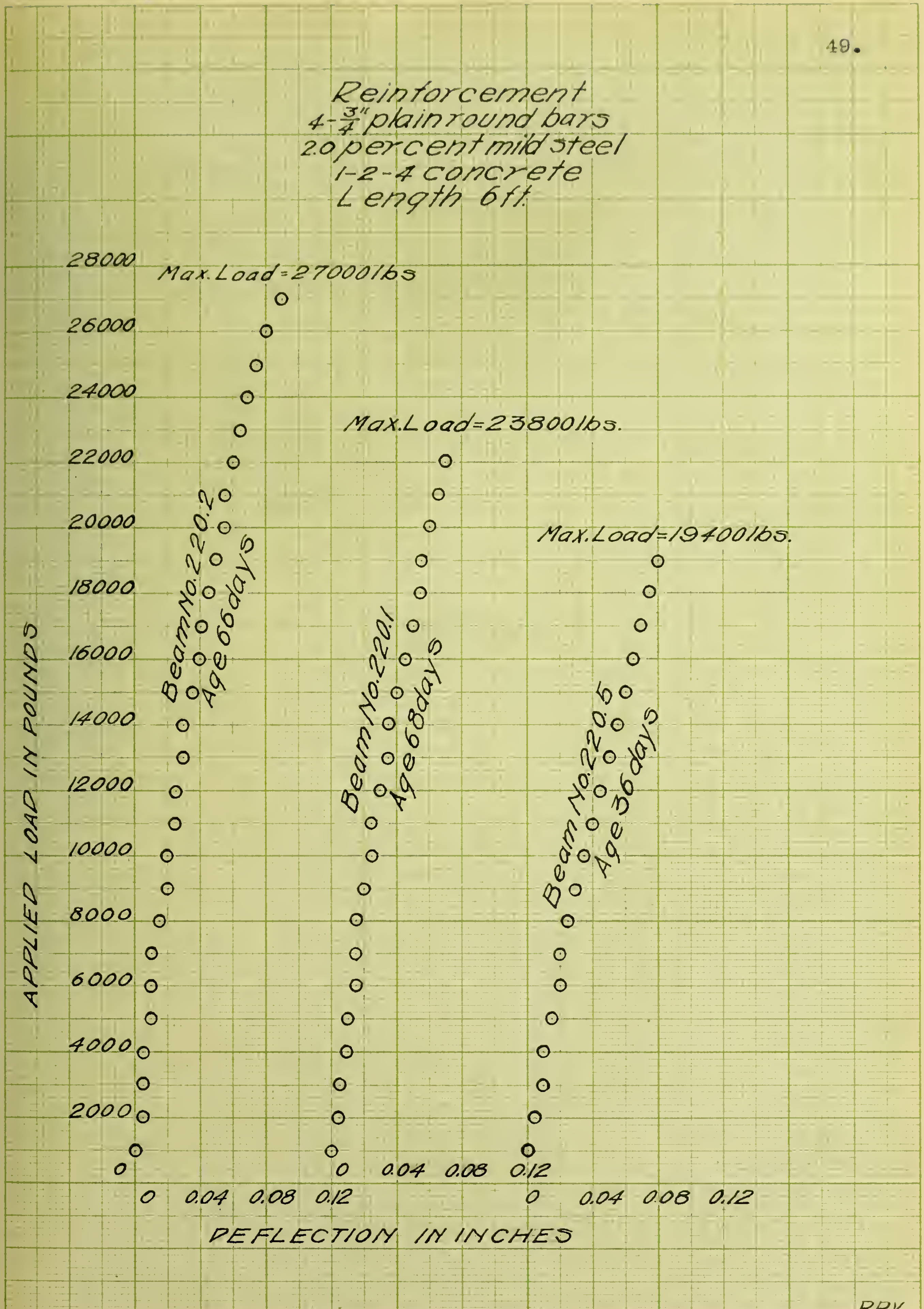


P.P.V.

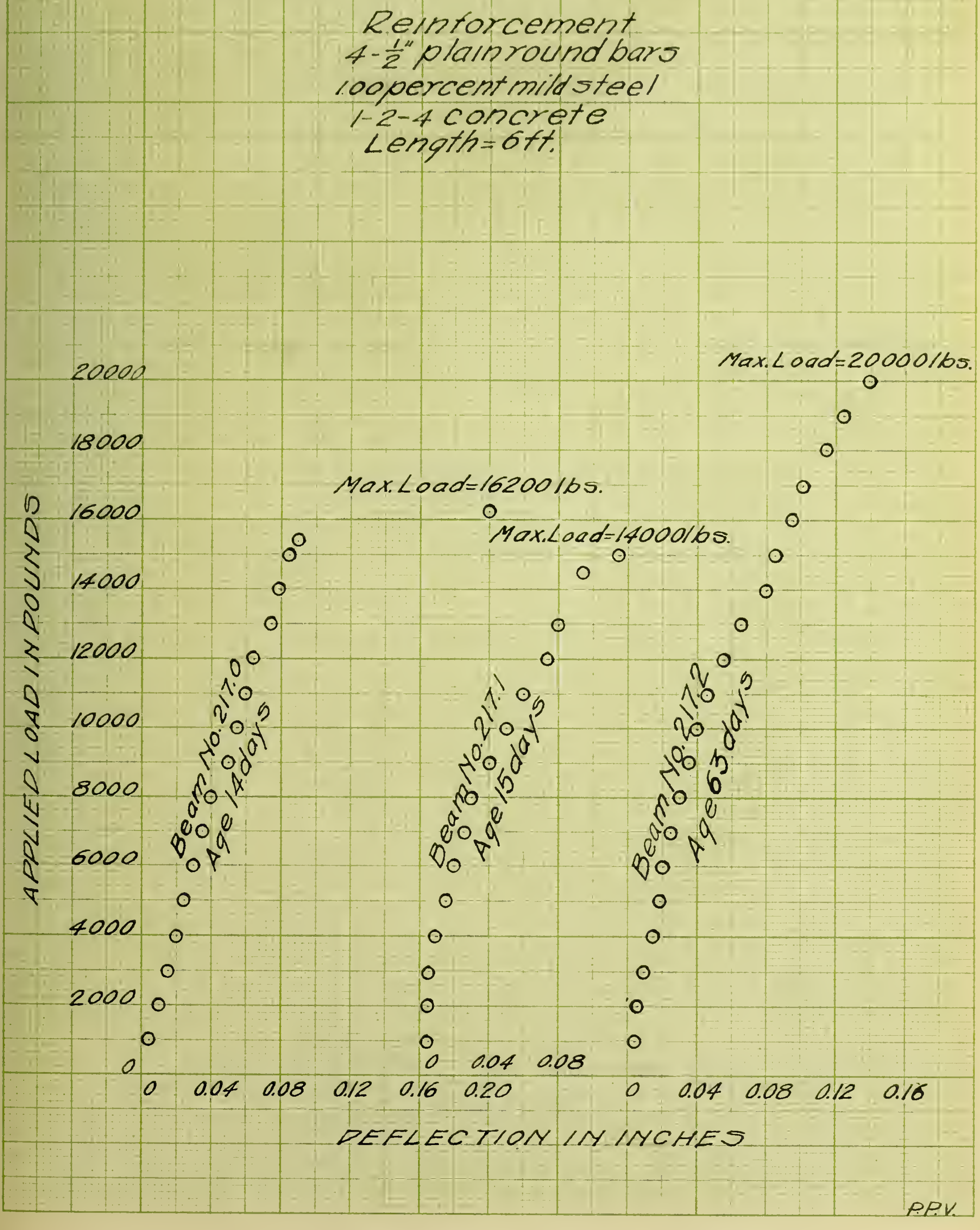

RELATION BETWEEN
LENGTH OF SPAN
AND
VERTICAL SHEARING UNIT-STRESS
ALL FAILURES BY DIAGONAL TENSION
1-2-4 CONCRETE
PLAIN ROUND MILD STEEL
6 FT. SPAN .98 % REINF.
8 " " 1.23 % "
10 " " 1.70 % "
12 " " 2.21 % "
VERTICAL SHEARING UNIT-STRESS
220
200
180
160
140
120
100
80
60
40
20
0
CORRECTED FOR
VARIATION OF REINF.
REDUCED TO .98 % REINF.
6
8
10
12
LENGTH OF SPAN IN FEET
P.P.V.


Reinforcement
4 ½" plainround bars
1.00 percent mild steel
1-2-4 concrete
Length 6 ft.
Max. Load = 24900 lbs.
Max. Load = 23000 lbs.
Max. Load = 16600 lbs
Max. Load 17300 lbs.
Beam No. 2/8.1 Age 64 days
Beam No. 2/8.2 Age 67 days
Beam No 2/8.3 Age 46 days
Beam 2/8.4 Age 61 days
APPLIED LOAD IN POUNDS
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 0.04 0.08 0.12 0.16
0 0.04 0.08 0.12
0 0.04 0.08 0.12
0 0.04 0.08
DEFLECTION IN INCHES
P.P.V.

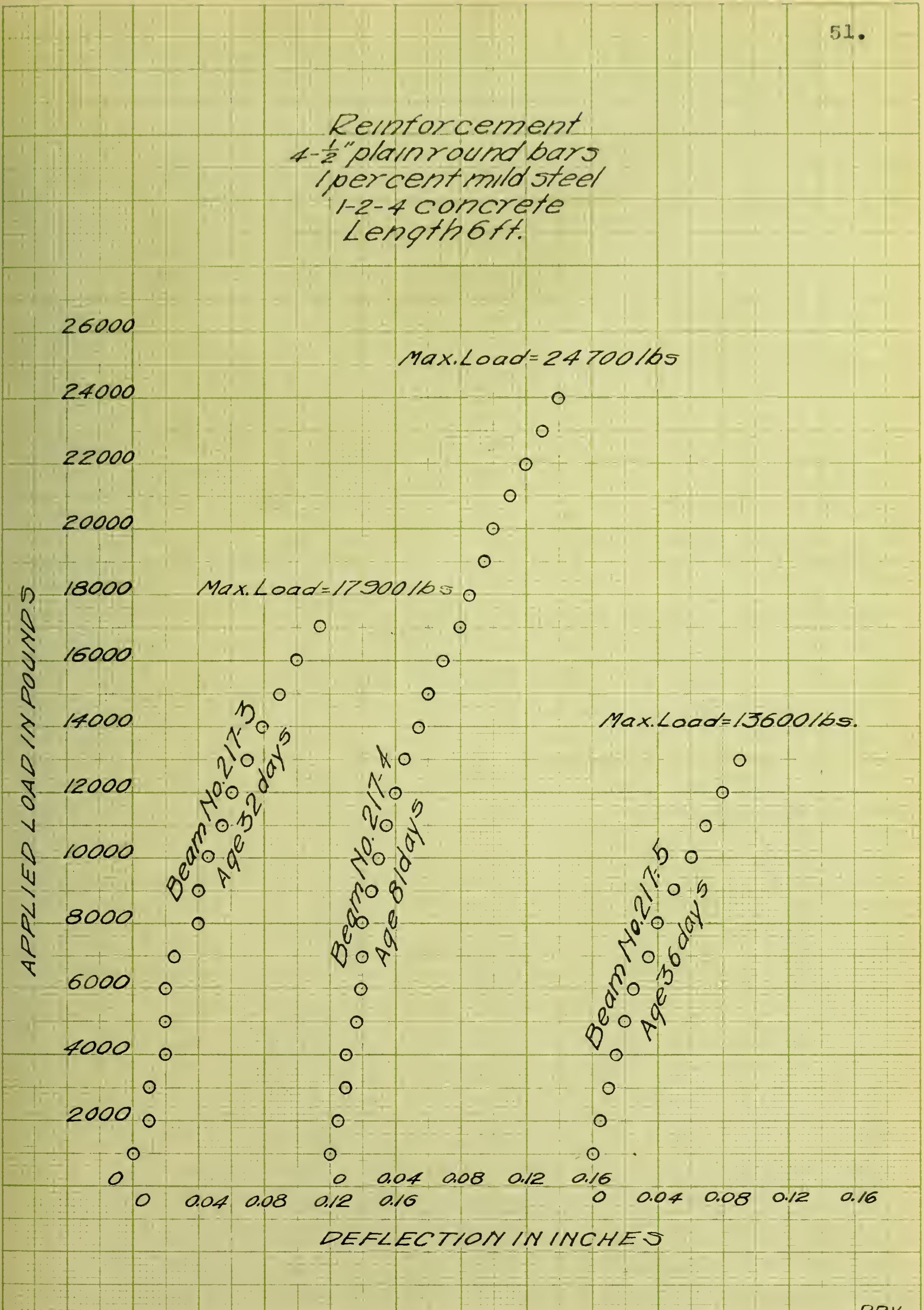

Reinforcement
6-½" plain round bars
1.5 percent mild steel.
1-2-4 concrete.
Length 6 ft.
Max. Load = 25200 lbs
Beam No. 219.1
Age 65 days
Max. Load = 21700 lbs.
Beam No. 219.2
Age 67 days
APPLIED LOAD IN POUNDS
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.04
0.08
0.12
0.16
0
0.04
0.08
0.12
DEFLECTION IN INCHES
P.P.V.

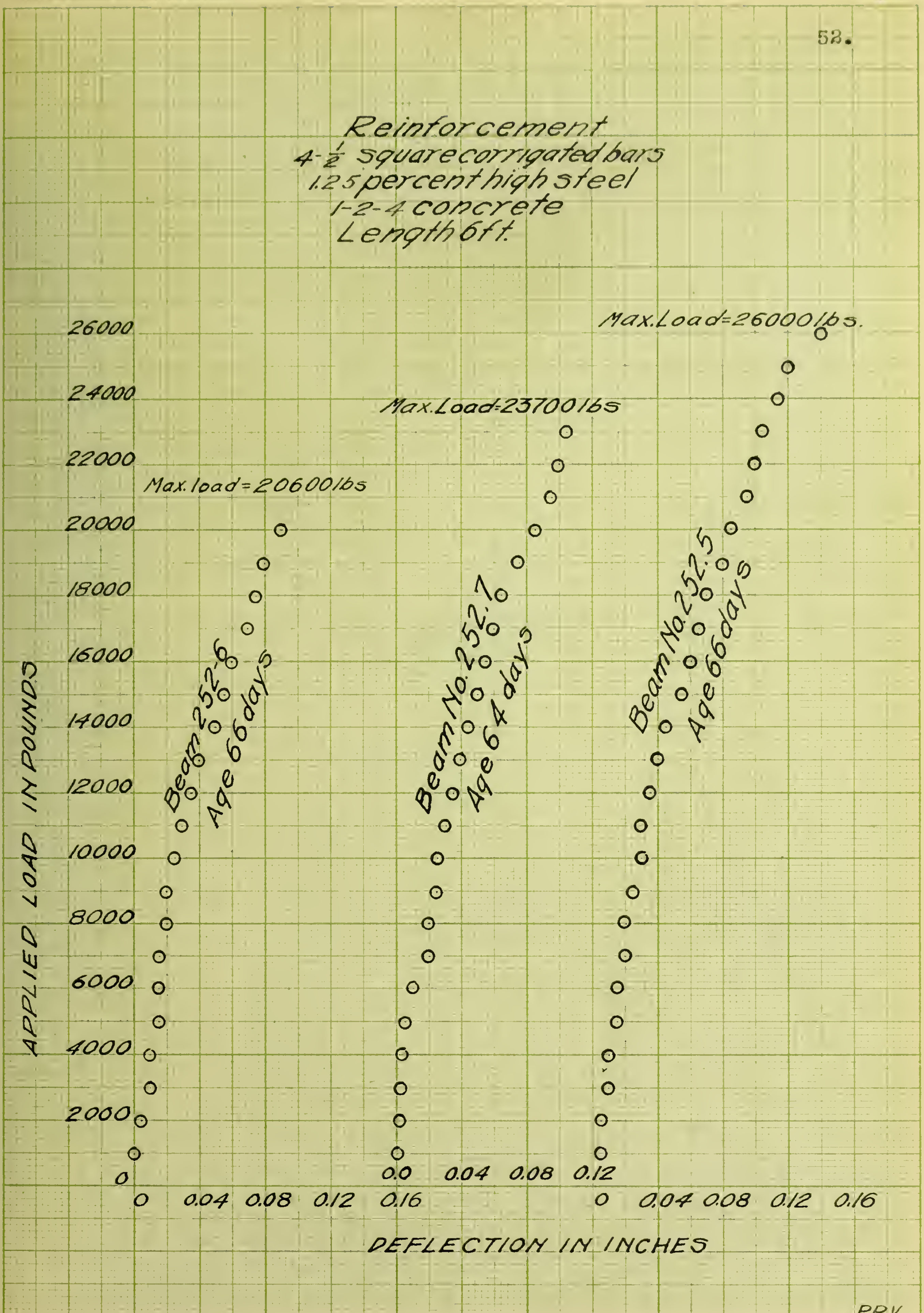


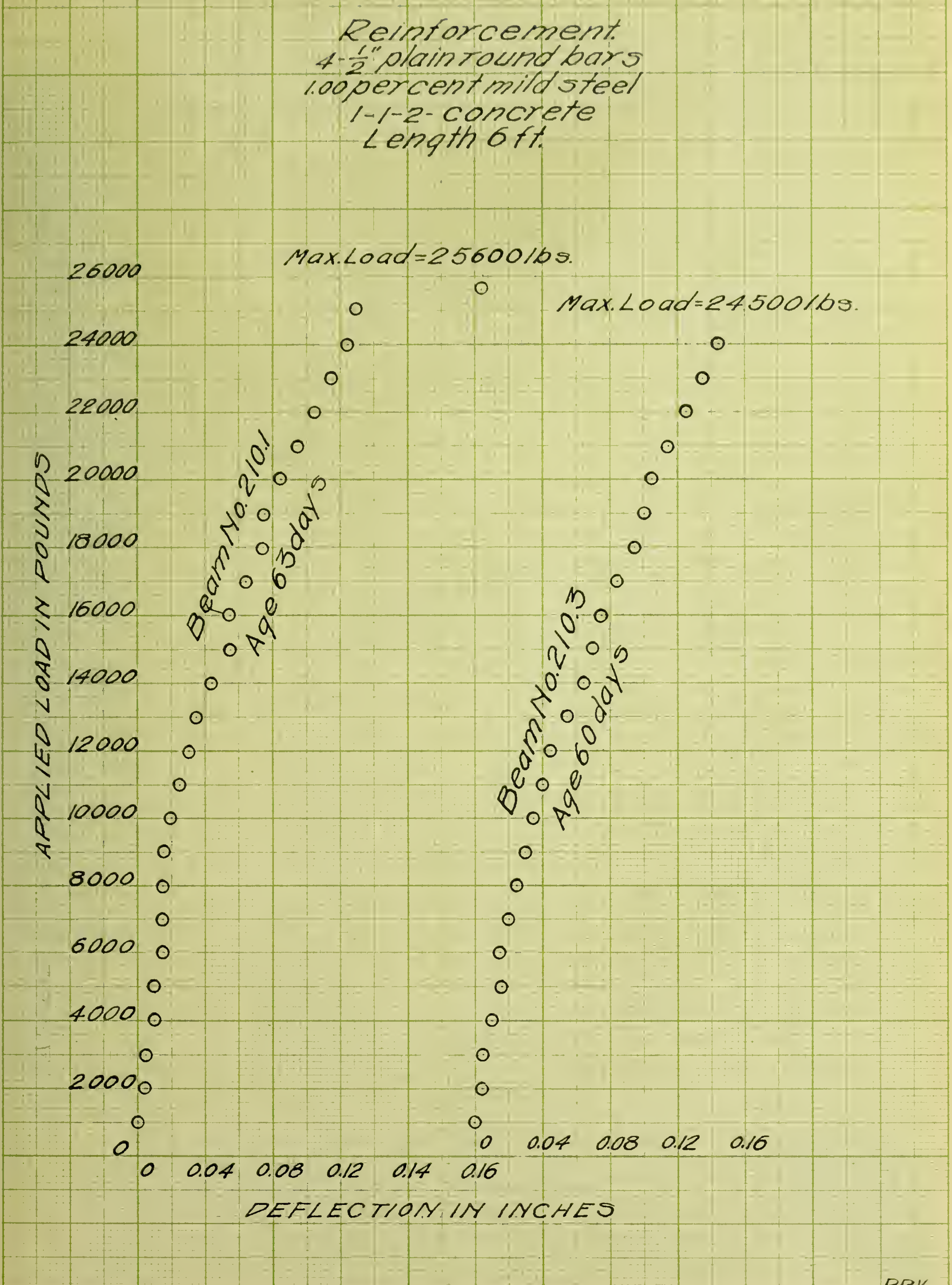
Reinforcement
4-3/4" plain round bars
2.0 percent mild steel
1-2-4 concrete
Length 6ft.
Max. Load=27000 lbs
Max. Load=23800 lbs.
Max. Load=19400 lbs.
Beam No. 220.2
Age 66 days
Beam No. 220.1
Age 68 days
Beam No. 220.5
Age 36 days
APPLIED LOAD IN POUNDS
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 0.04 0.08 0.12
0 0.04 0.08 0.12
0 0.04 0.08 0.12
DEFLECTION IN INCHES
P.P.V.

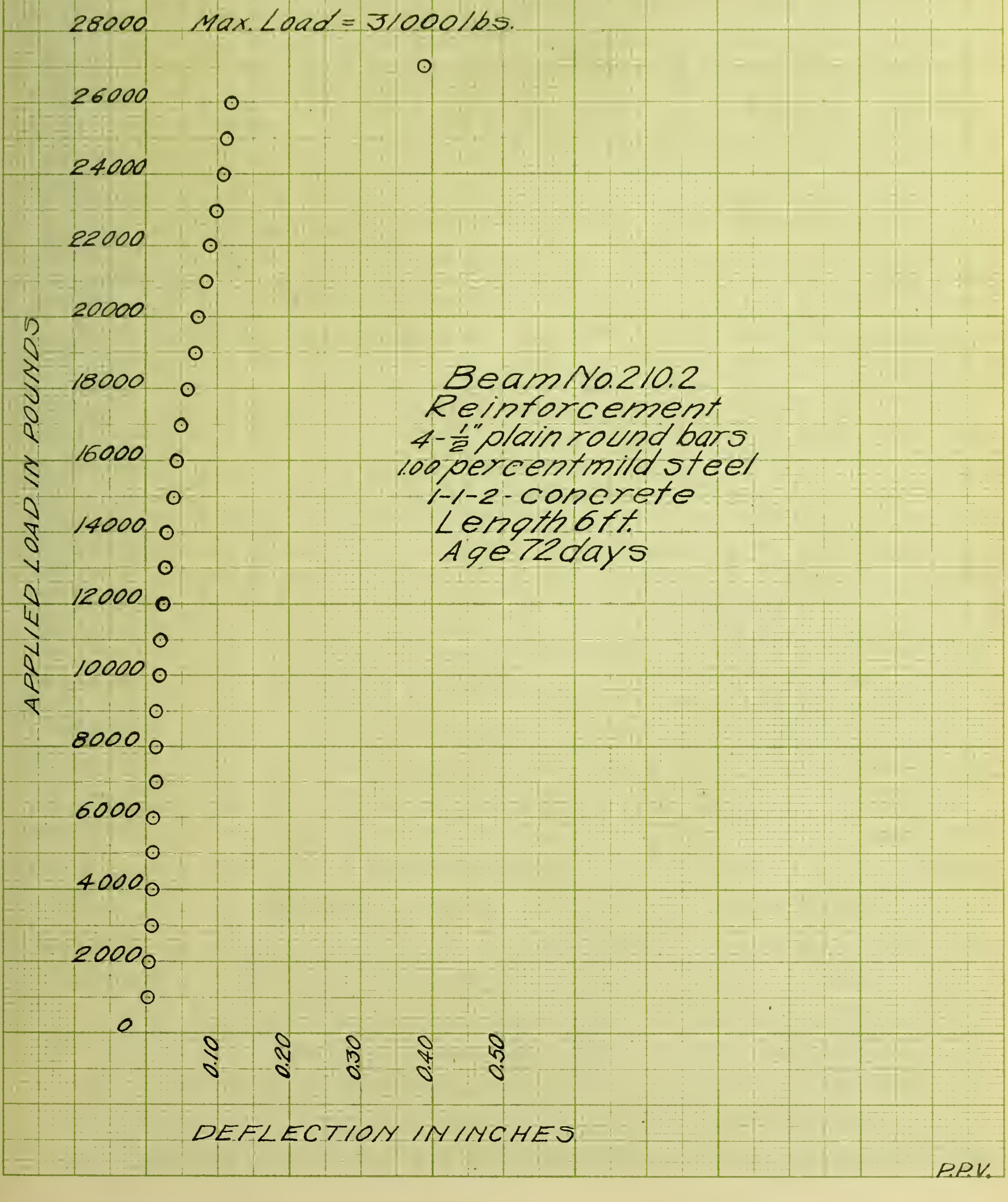


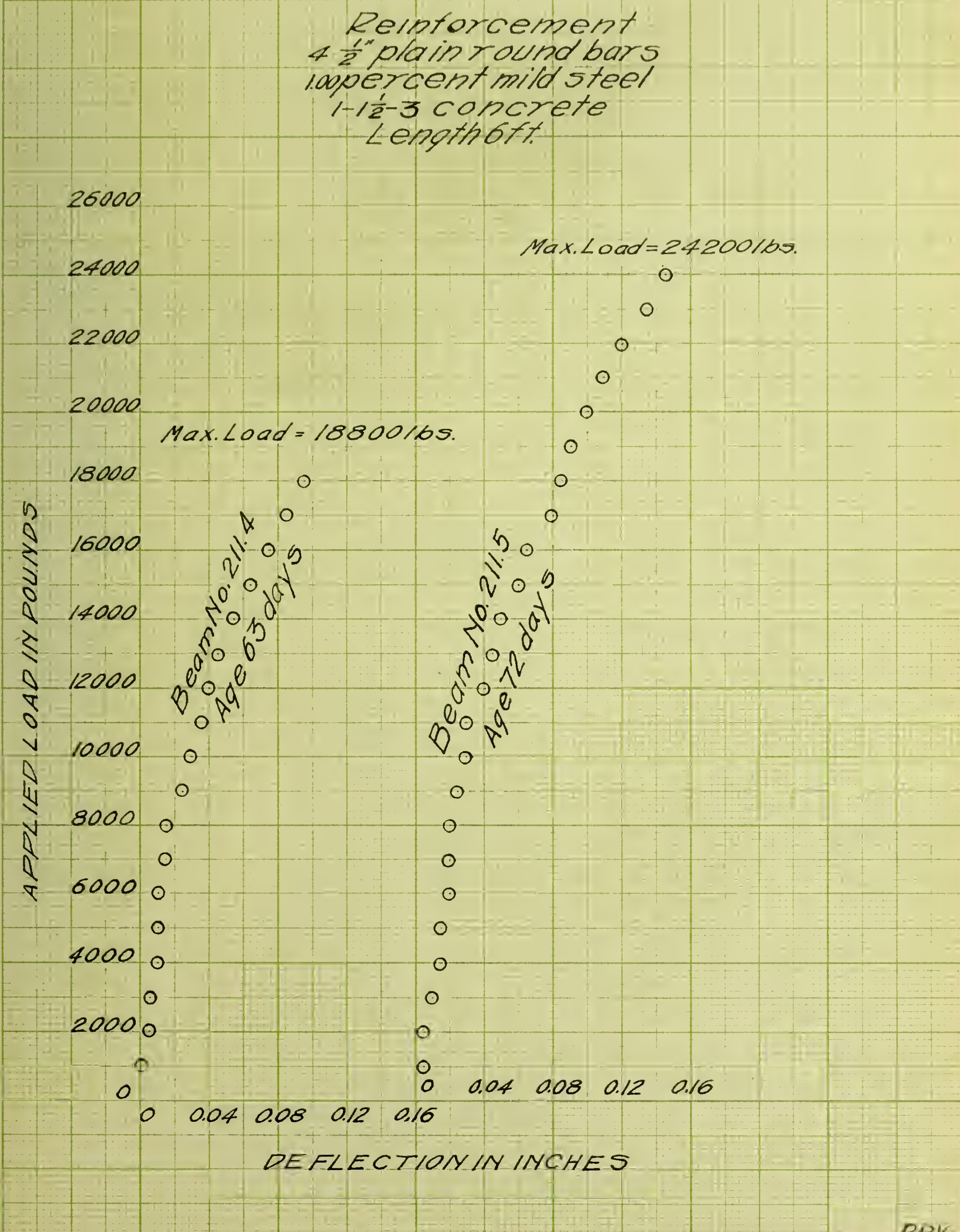
Reinforcement
4-½" plain round bars
100 percent mild steel
1-2-4 concrete
Length = 6 ft.
Max. Load = 20000 lbs.
Max. Load = 16200 lbs.
Max. Load = 14000 lbs.
Beam No. 217.0
Age 14 days
Beam No. 217.1
Age 15 days
Beam No. 217.2
Age 63 days
APPLIED LOAD IN POUNDS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0
0.04
0.08
0.12
0.16
0.20
0
0.04
0.08
0
0.04
0.08
0.12
0.16
DEFLECTION IN INCHES
P.P.V.

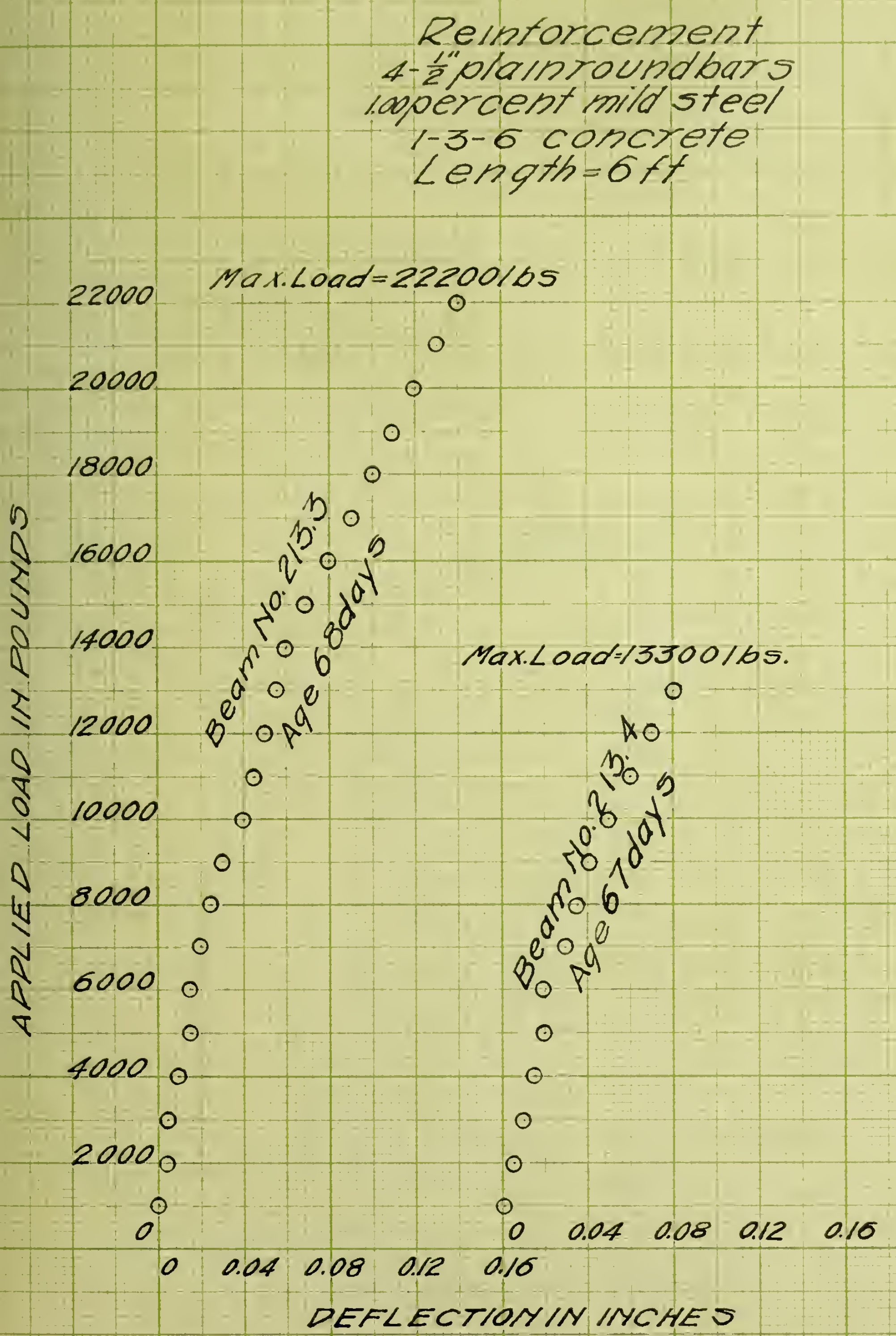

Reinforcement
4-½" plain round bars
1 percent mild steel
1-2-4 concrete
Length 6 ft.
Max. Load = 24700 lbs
Max. Load = 17900 lbs
Max. Load = 13600 lbs.
Beam No. 217-3 Age 32 days
Beam No. 217-4 Age 81 days
Beam No. 217-5 Age 36 days
APPLIED LOAD IN POUNDS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
26000
0 0.04 0.08 0.12 0.16
0 0.04 0.08 0.12 0.16
0 0.04 0.08 0.12 0.16
DEFLECTION IN INCHES
P.P.V.


Reinforcement
4-1/2 square corrigated bars
1.25 percent high steel
1-2-4 concrete
Length 6 ft.
Max. load = 20600 lbs
Max. Load = 23700 lbs
Max. Load = 26000 lbs.
Beam 252-6
Age 66 days
Beam No. 252.7
Age 64 days
Beam No. 252.5
Age 66 days
APPLIED LOAD IN POUNDS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
26000
0.0 0.04 0.08 0.12
0 0.04 0.08 0.12 0.16
0 0.04 0.08 0.12 0.16
DEFLECTION IN INCHES
P.P.V.

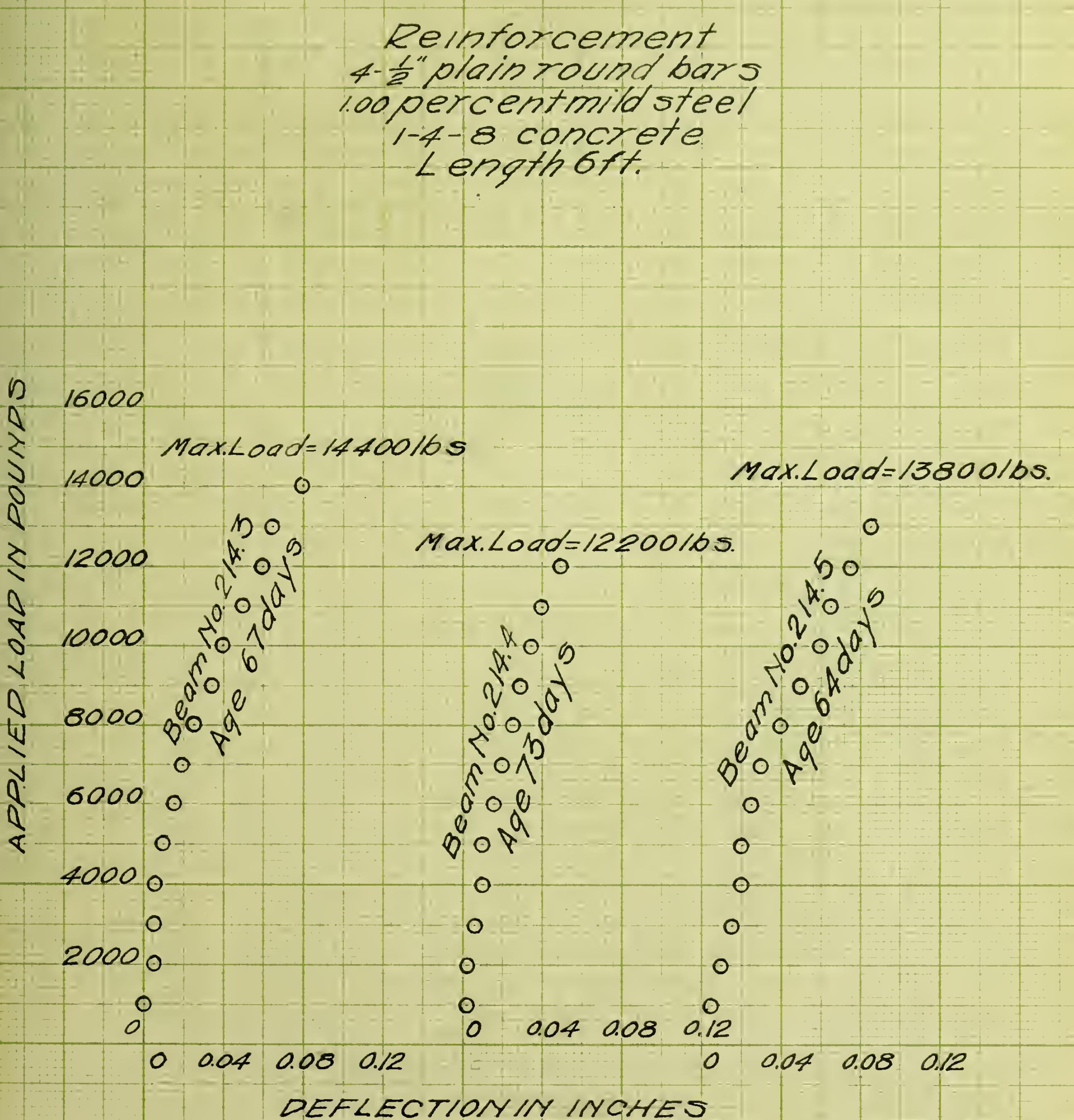

Reinforcement.
4-½" plain round bars
1.00 percent mild steel
1-1-2- concrete
Length 6 ft.
Max. Load = 25600 lbs.
Max. Load = 24500 lbs.
Beam No. 210.1
Age 63 days
Beam No. 210.3
Age 60 days
APPLIED LOAD IN POUNDS
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 0.04 0.08 0.12 0.14 0.16
0 0.04 0.08 0.12 0.16
DEFLECTION IN INCHES
P.P.V.


Max. Load = 31000 lbs.
Beam No. 210.2
Reinforcement
4-½" plain round bars
100 percent mild steel
1-1-2-concrete
Length 6 ft.
Age 72 days
APPLIED LOAD IN POUNDS
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0.10
0.20
0.30
0.40
0.50
DEFLECTION IN INCHES
P.P.V.

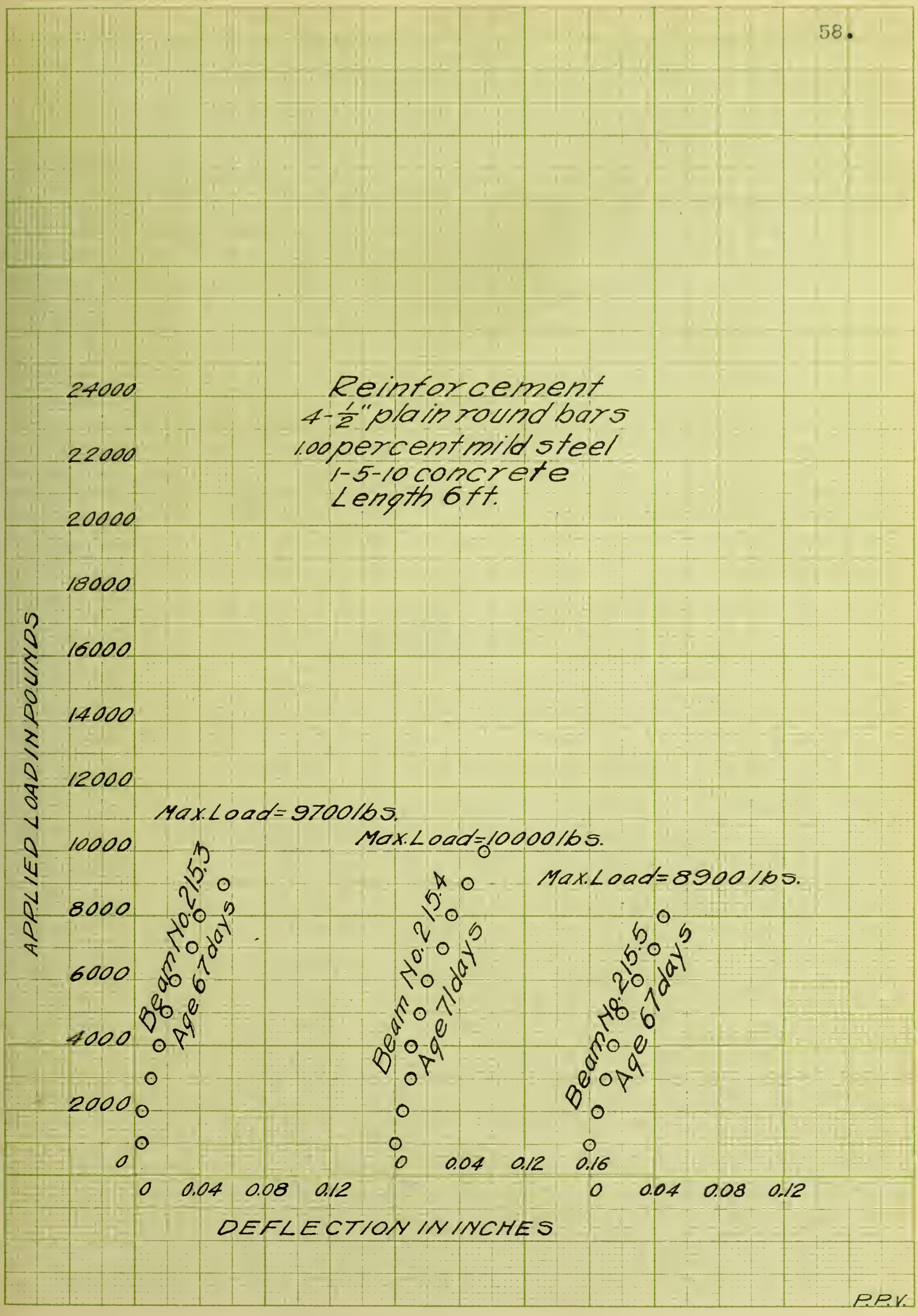

Reinforcement
4 1/2" plain round bars
1.00 percent mild steel
1-1 1/2-3 concrete
Length 6 ft.
Max. Load = 24200 lbs.
Max. Load = 18800 lbs.
Beam No. 211.4
Age 63 days
Beam No. 211.5
Age 72 days
APPLIED LOAD IN POUNDS
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.04
0.08
0.12
0.16
0
0.04
0.08
0.12
0.16
DEFLECTION IN INCHES
P.P.K.

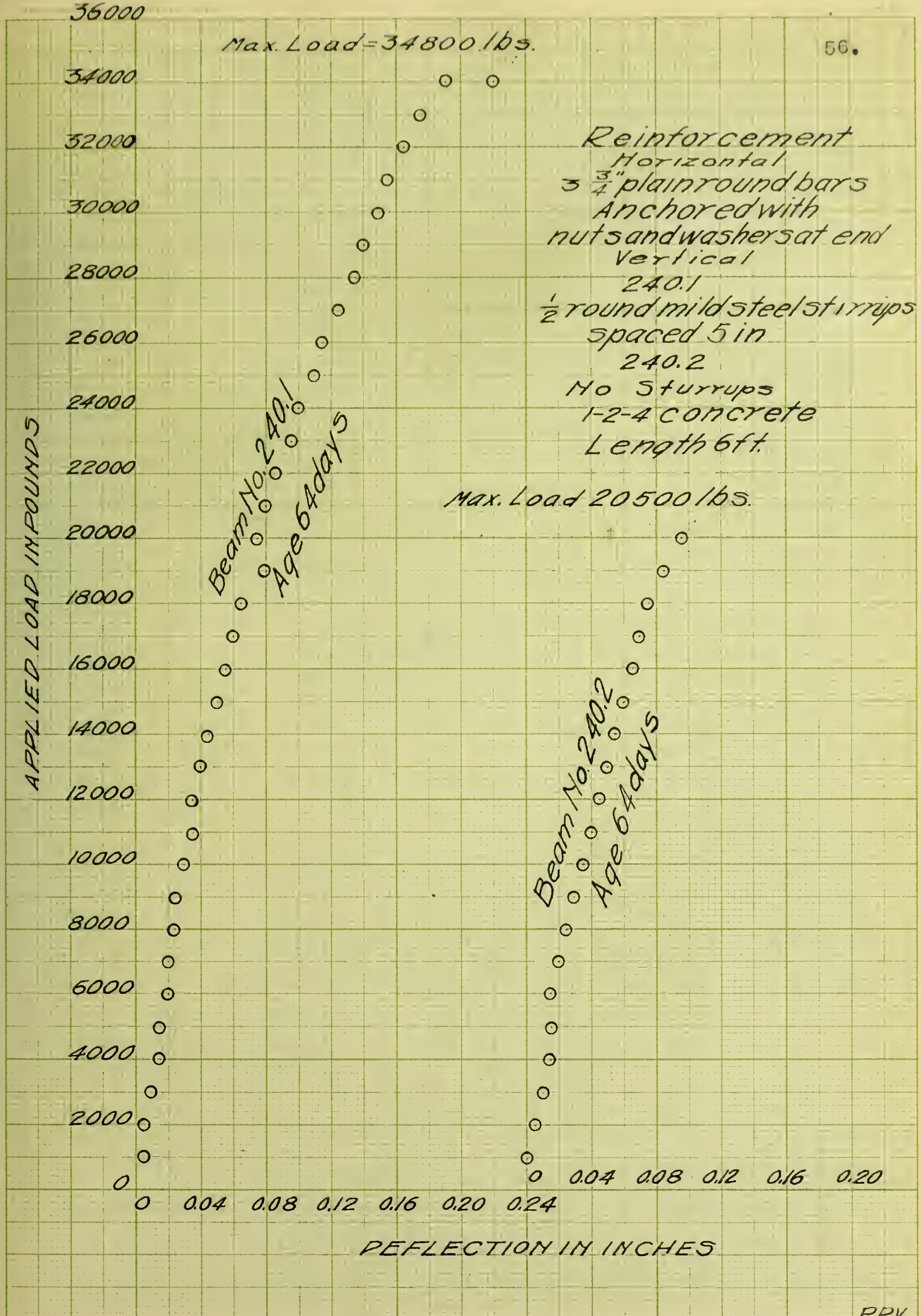

Reinforcement
4-½" plain round bars
1.00 percent mild steel
1-3-6 concrete
Length = 6 ft
Max. Load = 22200 lbs
Max. Load = 13300 lbs.
Beam No. 213.3
Age 68 days
Beam No. 213.4
Age 67 days
APPLIED LOAD IN POUNDS
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.04
0.08
0.12
0.16
0
0.04
0.08
0.12
0.16
DEFLECTION IN INCHES

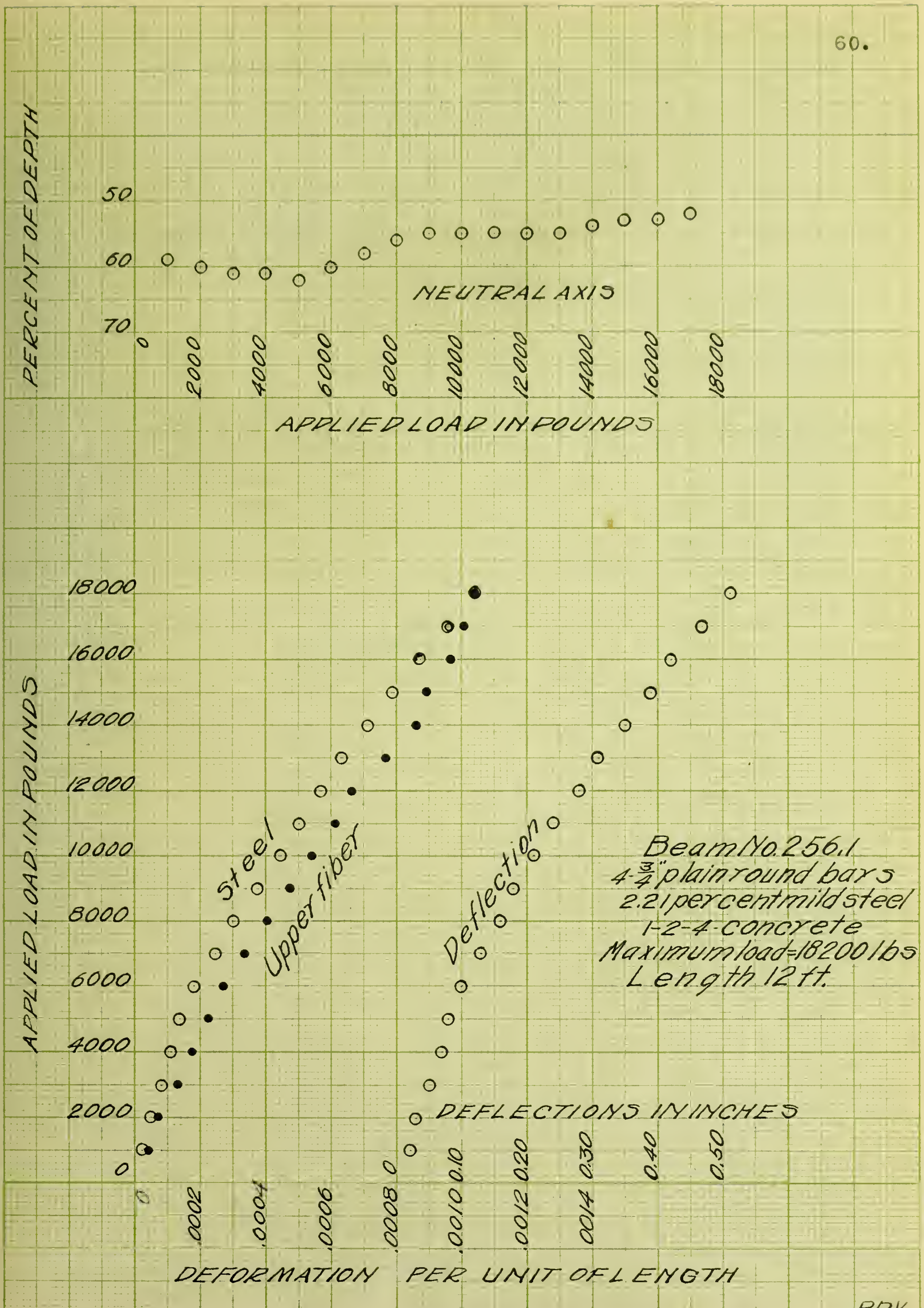
P.P.V.

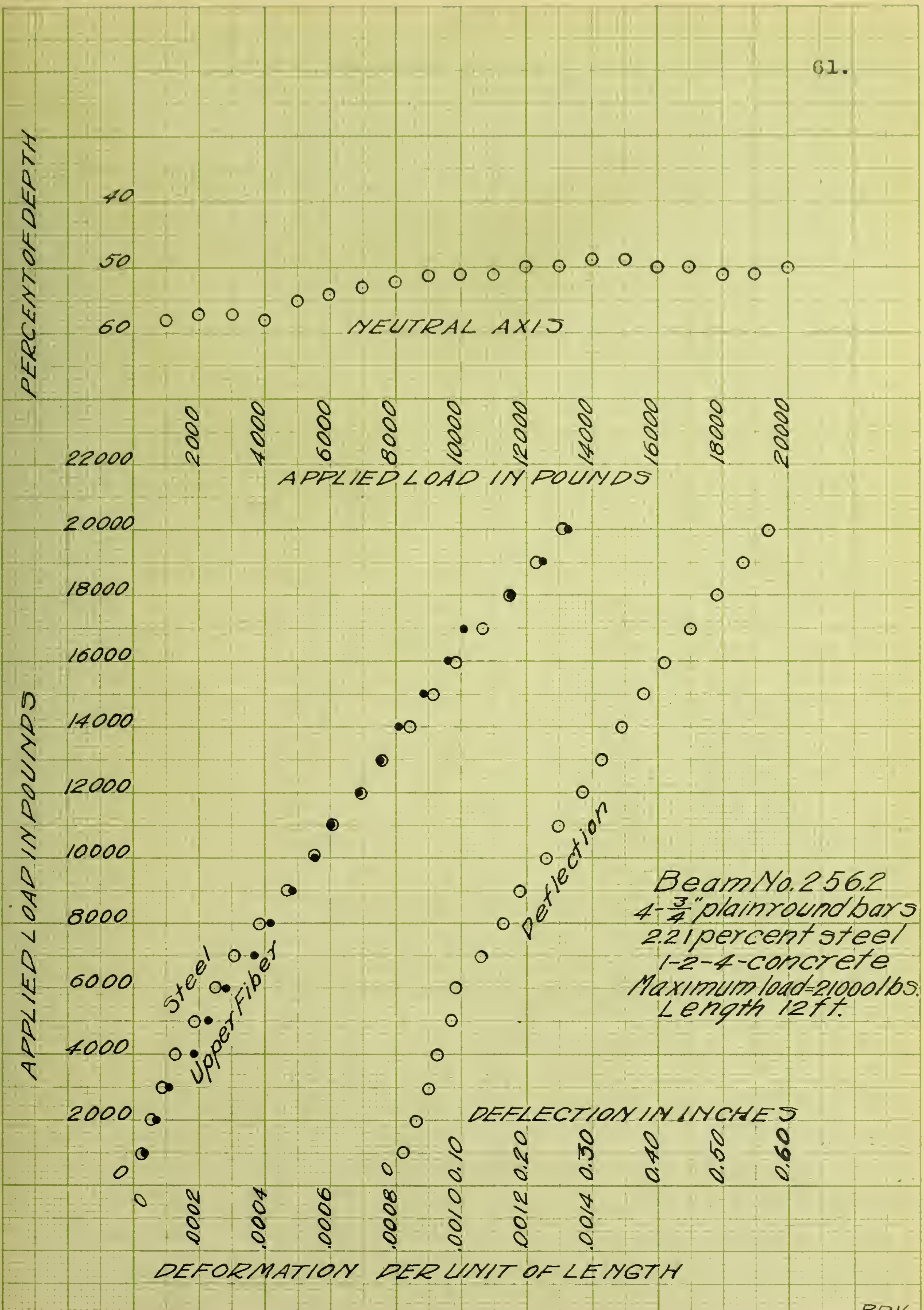

Reinforcement
4-½" plain round bars
1.00 percent mild steel
1-4-8 concrete
Length 6 ft.
APPLIED LOAD IN POUNDS
16000
14000
12000
10000
8000
6000
4000
2000
0
Max. Load = 14400 lbs
Beam No. 214.3
Age 67 days
Max. Load = 12200 lbs.
Beam No. 214.4
Age 73 days
Max. Load = 13800 lbs.
Beam No. 214.5
Age 64 days
0 0.04 0.08 0.12
0 0.04 0.08 0.12
0 0.04 0.08 0.12
DEFLECTION IN INCHES

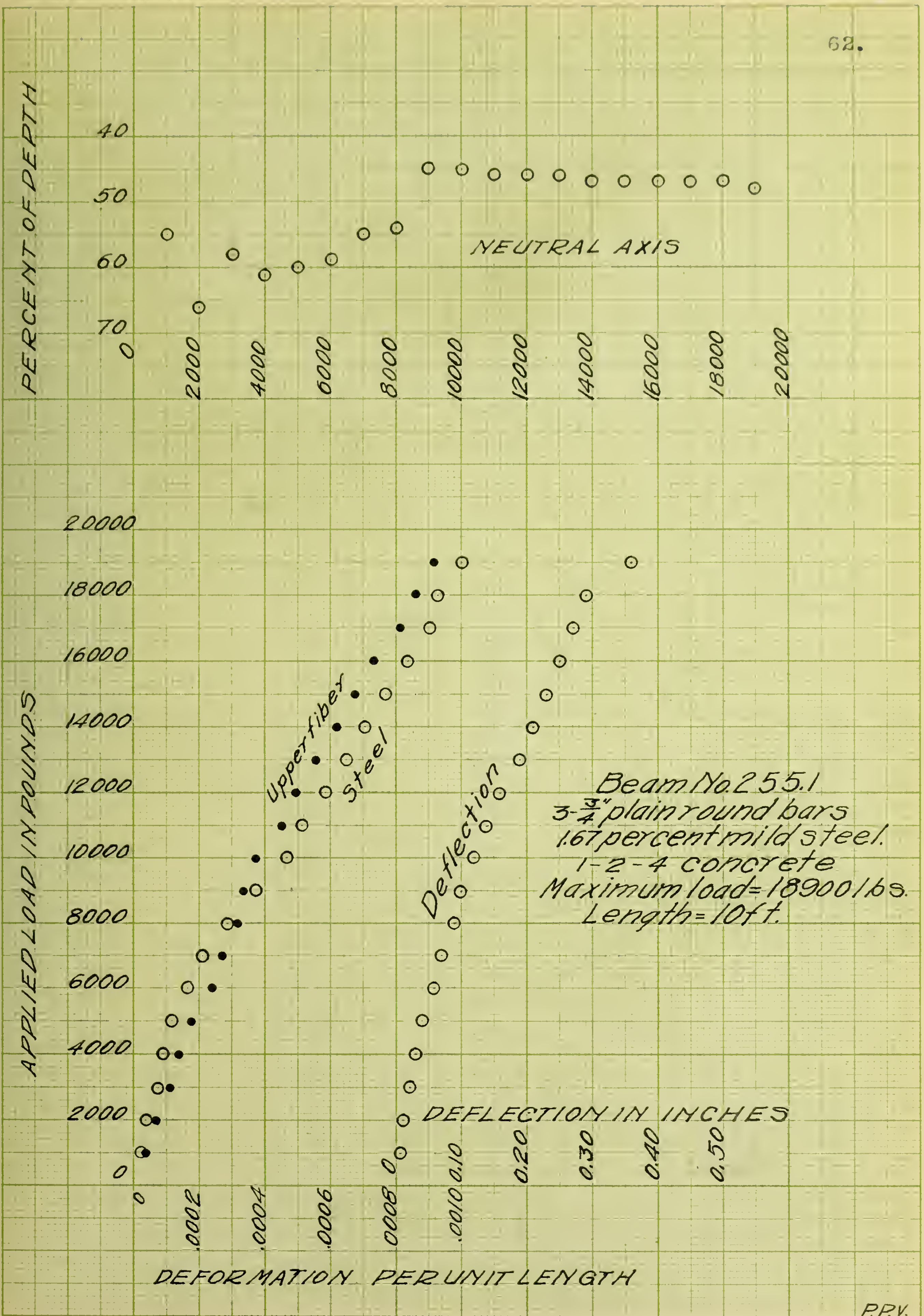
P.P.V.

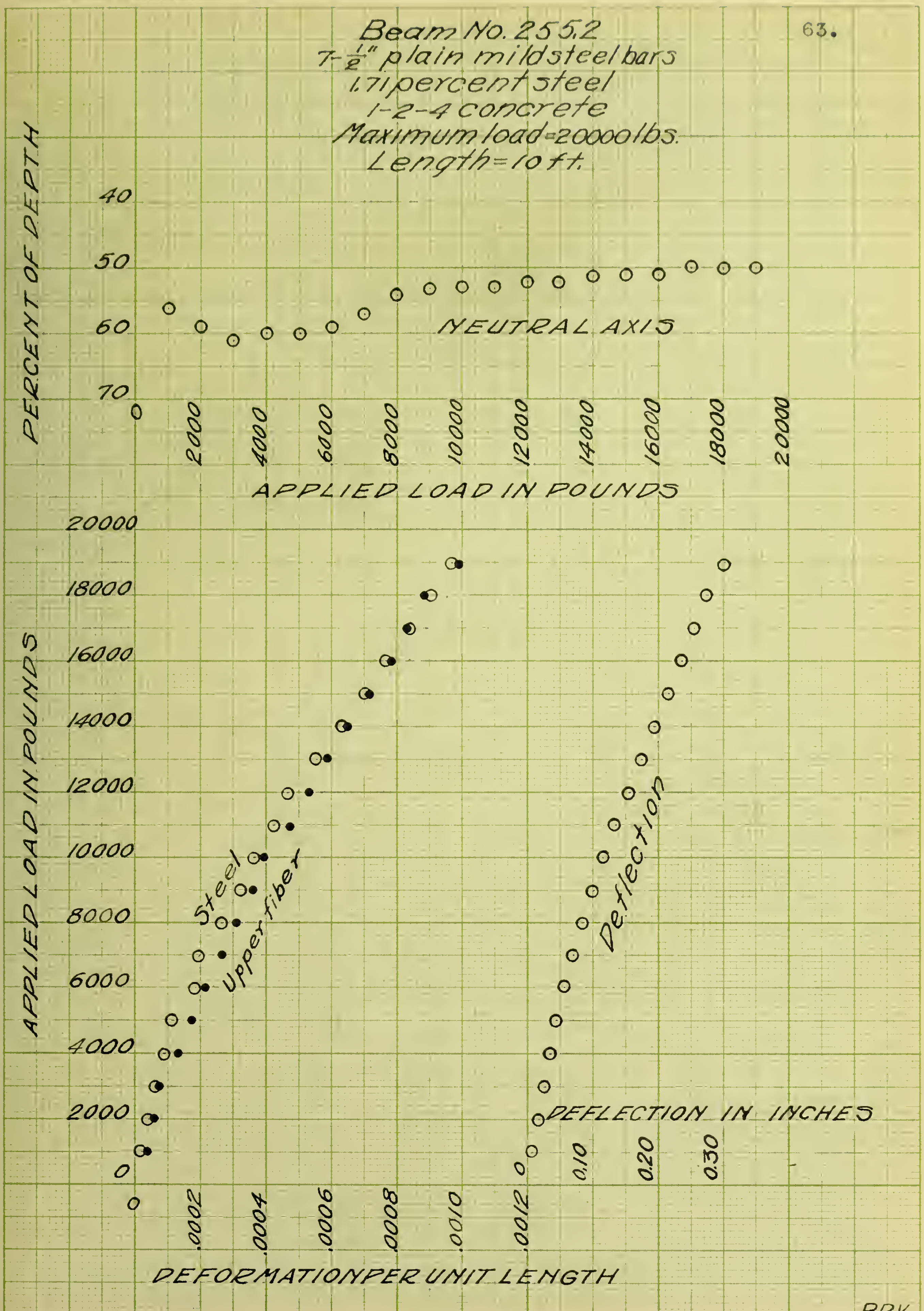

Reinforcement
4-½" plain round bars
1.00 percent mild steel
1-5-10 concrete
Length 6 ft.
APPLIED LOAD IN POUNDS
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Max. Load = 9700 lbs.
Beam No. 215.3
Age 67 days
Max. Load = 10000 lbs.
Beam No. 215.4
Age 71 days
Max. Load = 8900 lbs.
Beam No. 215.5
Age 67 days
0
0.04
0.12
0.16
0
0.04
0.08
0.12
0
0.04
0.08
0.12
DEFLECTION IN INCHES
P.P.V.

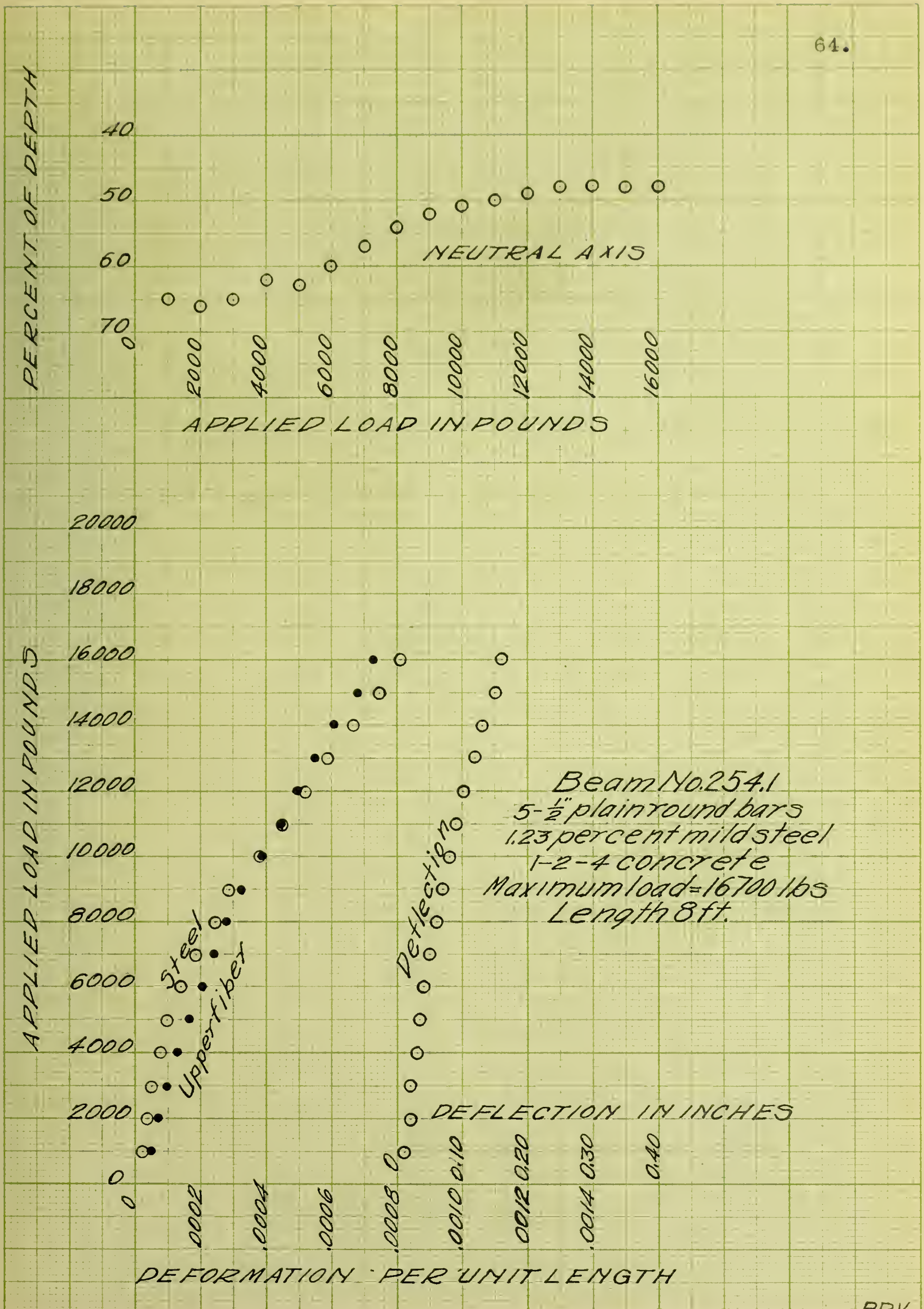

Max. Load = 34800 lbs.
Reinforcement
Horizontal
3 3/4" plain round bars
Anchored with
nuts and washers at end
Vertical
240.1
1/2 round mild steel stirrups
spaced 5 in
240.2
No Sturrups
1-2-4 concrete
Length 6 ft.
Max. Load 20500 lbs.
Beam No. 240.1
Age 64 days
Beam No. 240.2
Age 64 days
APPLIED LOAD IN POUNDS
DEFLECTION IN INCHES
36000
34000
32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 0.04 0.08 0.12 0.16 0.20 0.24
0 0.04 0.08 0.12 0.16 0.20
P.P.V.

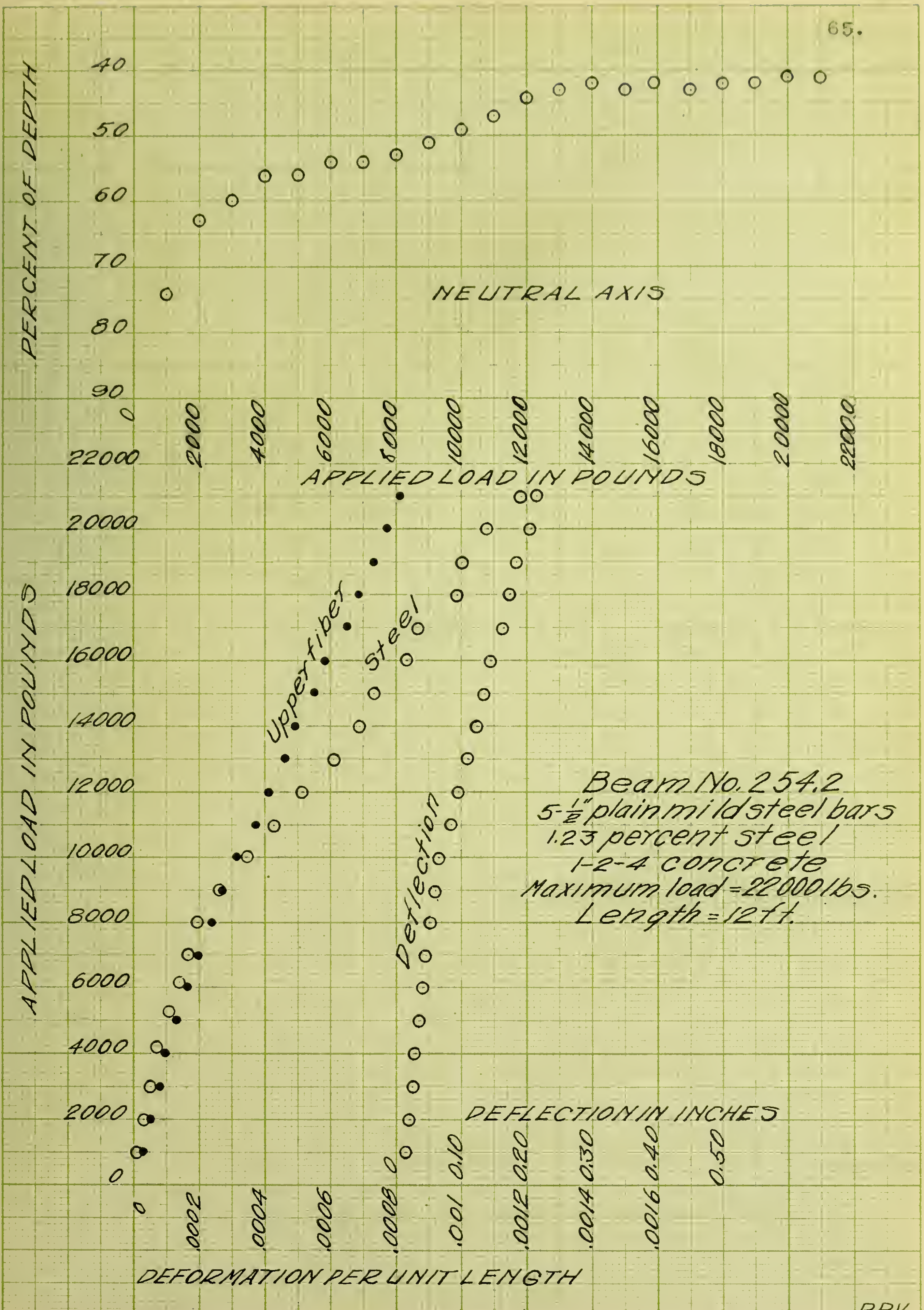

PERCENT OF DEPTH
50
60
70
NEUTRAL AXIS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
APPLIED LOAD IN POUNDS
APPLIED LOAD IN POUNDS
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Steel
Upper fiber
Deflection
Beam No. 256.1
4-3/4" plain round bars
2.21 percent mild steel
1-2-4-concrete
Maximum load=18200 lbs
Length 12 ft.
DEFLECTIONS IN INCHES
0
0.10
0.20
0.30
0.40
0.50
0
.0002
.0004
.0006
.0008
.0010
.0012
.0014
DEFORMATION PER UNIT OF LENGTH
P.P.V.

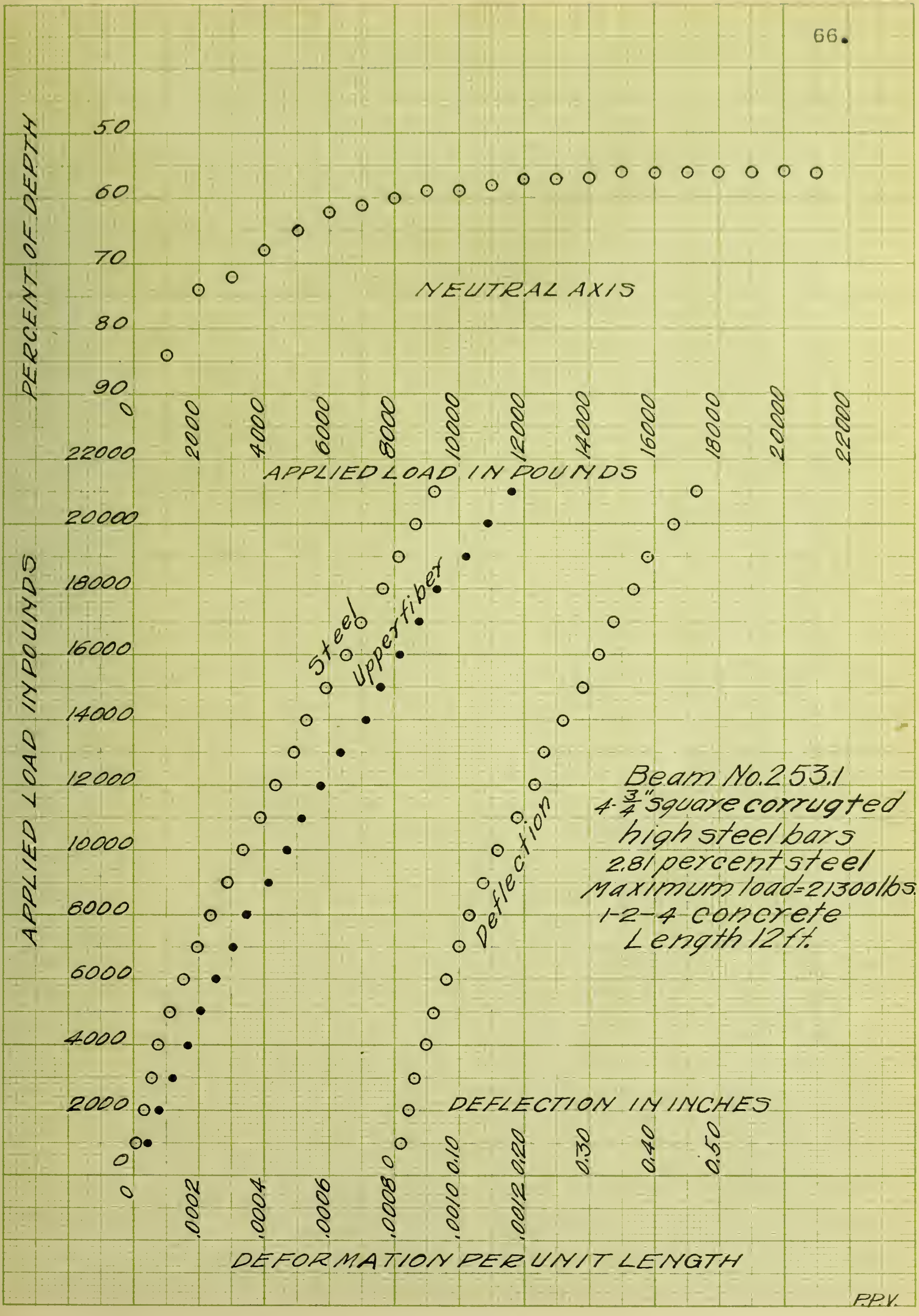

PERCENT OF DEPTH
40
50
60
NEUTRAL AXIS
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
APPLIED LOAD IN POUNDS
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
APPLIED LOAD IN POUNDS
Steel
Upper Fiber
Deflection
Beam No. 256.2
4-$\frac{3}{4}$" plain round bars
2.21 percent steel
1-2-4-concrete
Maximum load=21000 lbs.
Length 12 ft.
DEFLECTION IN INCHES
0
0.10
0.20
0.30
0.40
0.50
0.60
0
.0002
.0004
.0006
.0008
.0010
.0012
.0014
DEFORMATION PER UNIT OF LENGTH
P.P.V.

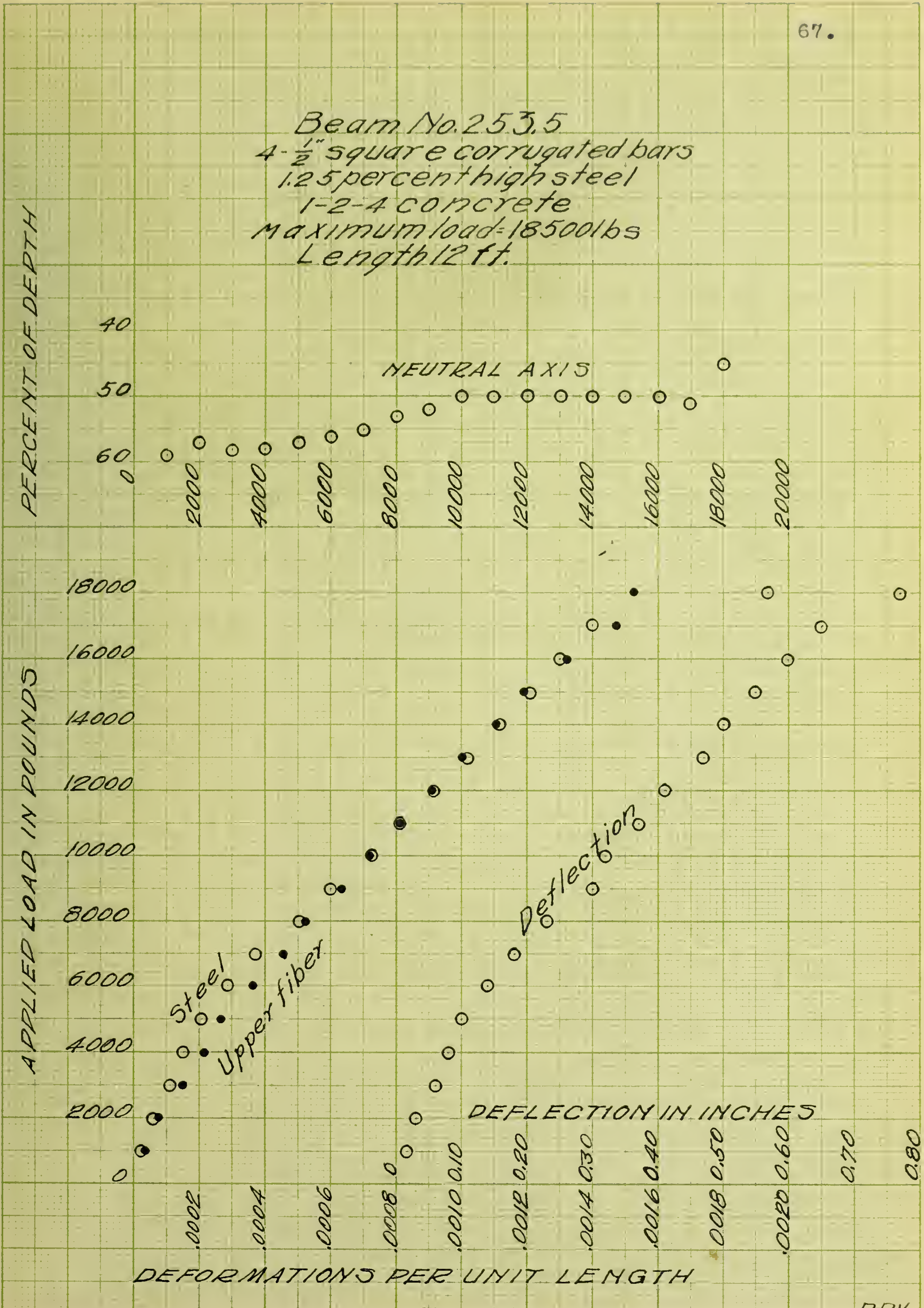

PERCENT OF DEPTH
40
50
60
70
NEUTRAL AXIS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
APPLIED LOAD IN POUNDS
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Upper fiber
steel
Deflection
Beam No. 255.1
3-3/4" plain round bars
1.67 percent mild steel.
1-2-4 concrete
Maximum load=18900 lbs.
Length=10 ft.
DEFLECTION IN INCHES
0
0.10
0.20
0.30
0.40
0.50
0
.0002
.0004
.0006
.0008
.0010
DEFORMATION PER UNIT LENGTH
P.P.V.

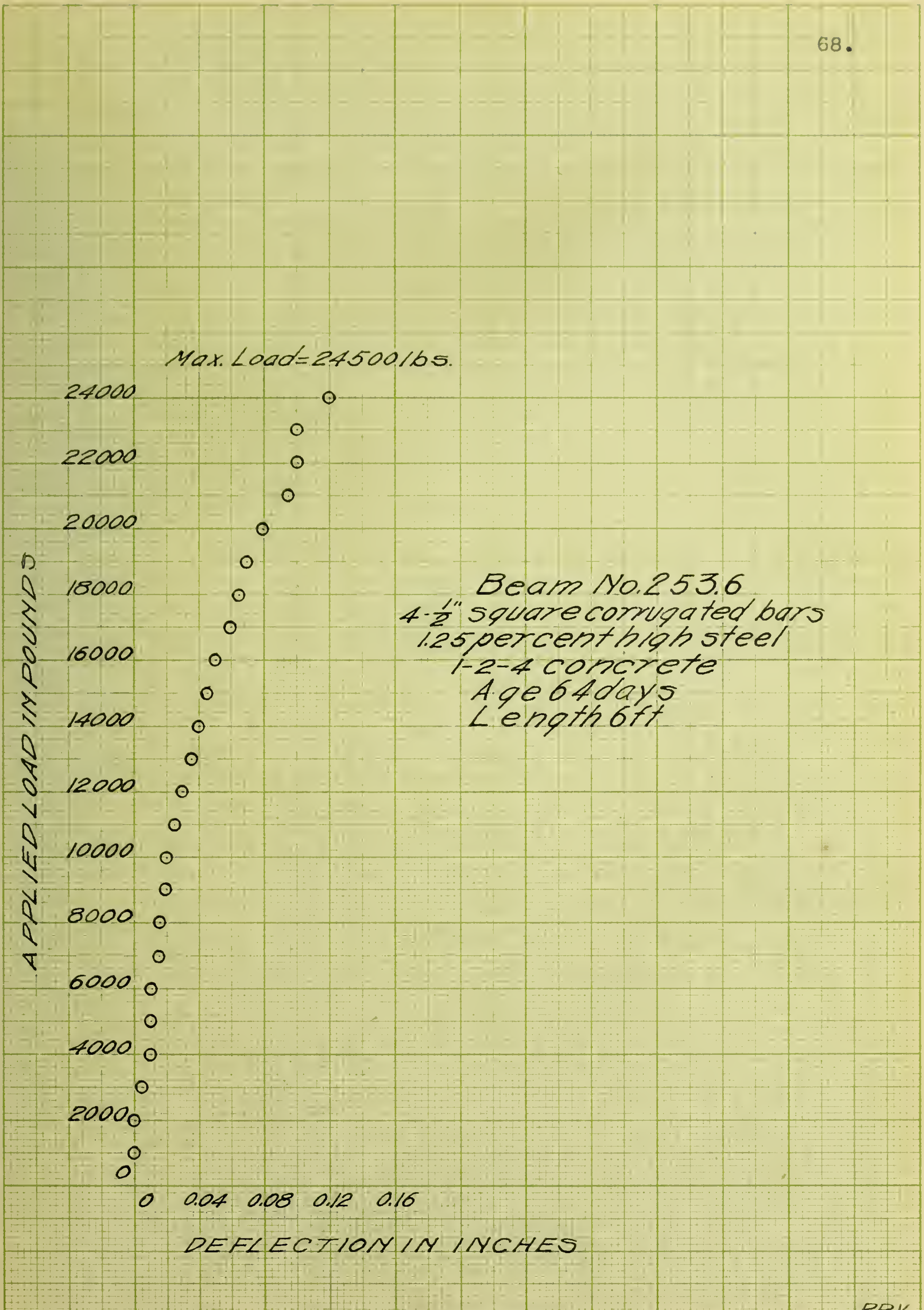

Beam No. 255.2
7-½" plain mild steel bars
1.71 percent steel
1-2-4 concrete
Maximum load = 20000 lbs.
Length = 10 ft.
PERCENT OF DEPTH
40
50
60
70
NEUTRAL AXIS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
APPLIED LOAD IN POUNDS
APPLIED LOAD IN POUNDS
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Steel
Upper fiber
Deflection
DEFLECTION IN INCHES
0
0.10
0.20
0.30
0
.0002
.0004
.0006
.0008
.0010
.0012
DEFORMATION PER UNIT LENGTH
P.P.V.

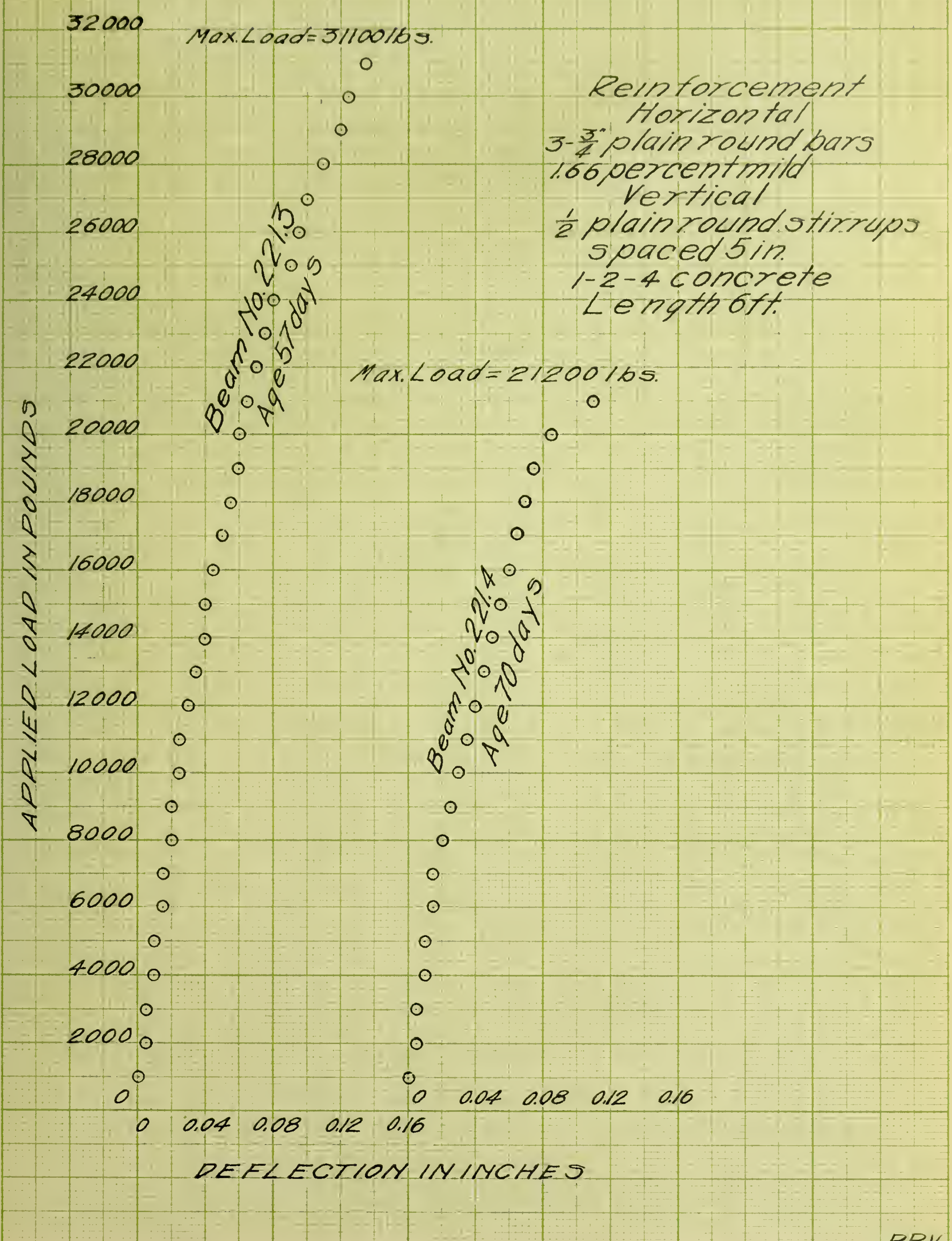

PERCENT OF DEPTH
40
50
60
70
NEUTRAL AXIS
0
2000
4000
6000
8000
10000
12000
14000
16000
APPLIED LOAD IN POUNDS
APPLIED LOAD IN POUNDS
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Steel
Upper fiber
Deflection
Beam No. 254.1
5-½" plain round bars
1.23 percent mild steel
1-2-4 concrete
Maximum load=16700 lbs
Length 8 ft.
DEFLECTION IN INCHES
0
0.10
0.20
0.30
0.40
0
.0002
.0004
.0006
.0008
.0010
.0012
.0014
DEFORMATION PER UNIT LENGTH
P.P.V.

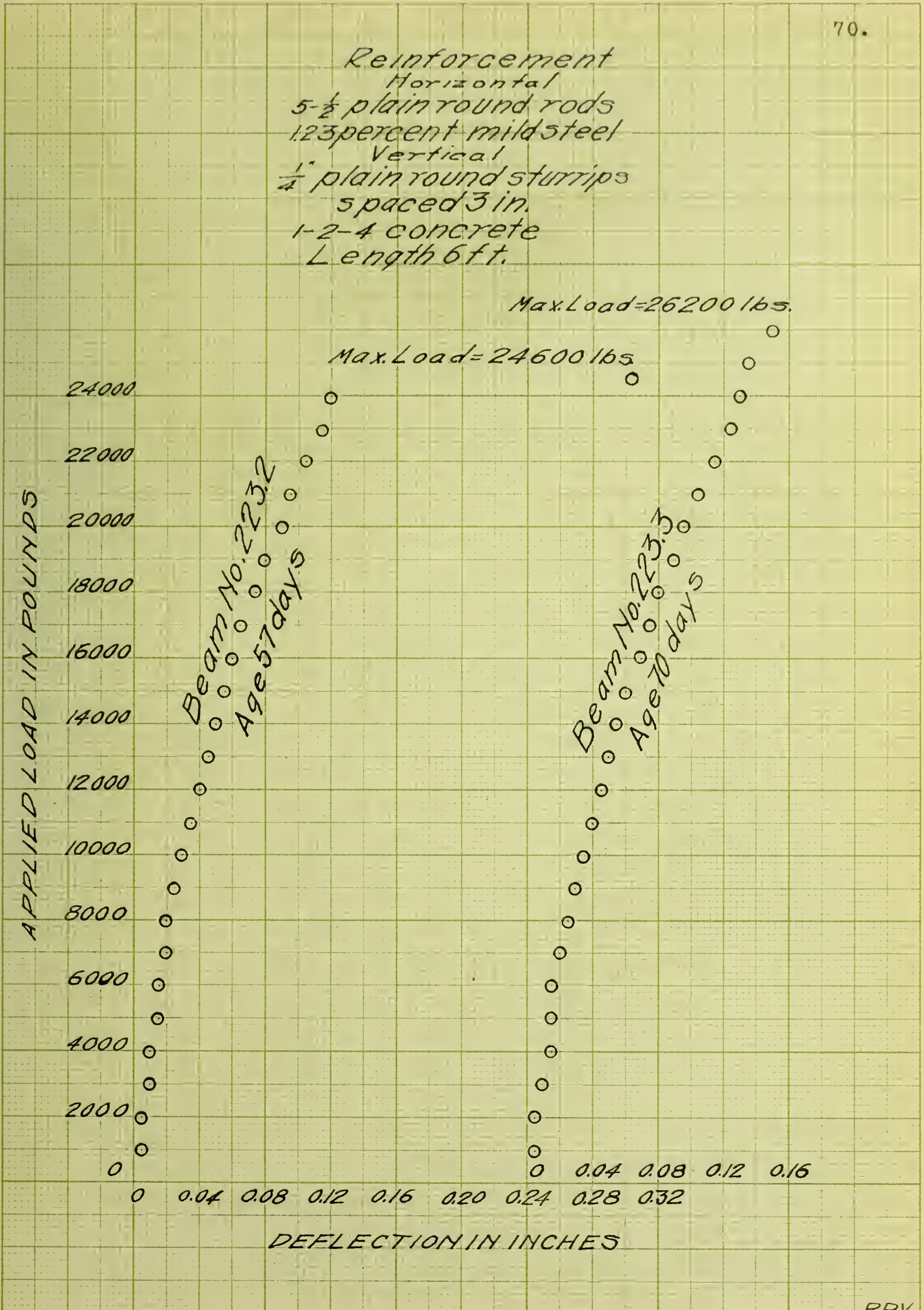

PERCENT OF DEPTH
40
50
60
70
80
90
NEUTRAL AXIS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
APPLIED LOAD IN POUNDS
APPLIED LOAD IN POUNDS
Upper fiber
Steel
Deflection
Beam No. 254.2
5-1/2" plain mild steel bars
1.23 percent steel
1-2-4 concrete
Maximum load = 22000 lbs.
Length = 12 ft.
DEFLECTION IN INCHES
0
0.10
0.20
0.30
0.40
0.50
0
.0002
.0004
.0006
.0008
.001
.0012
.0014
.0016
DEFORMATION PER UNIT LENGTH
P.P.V.

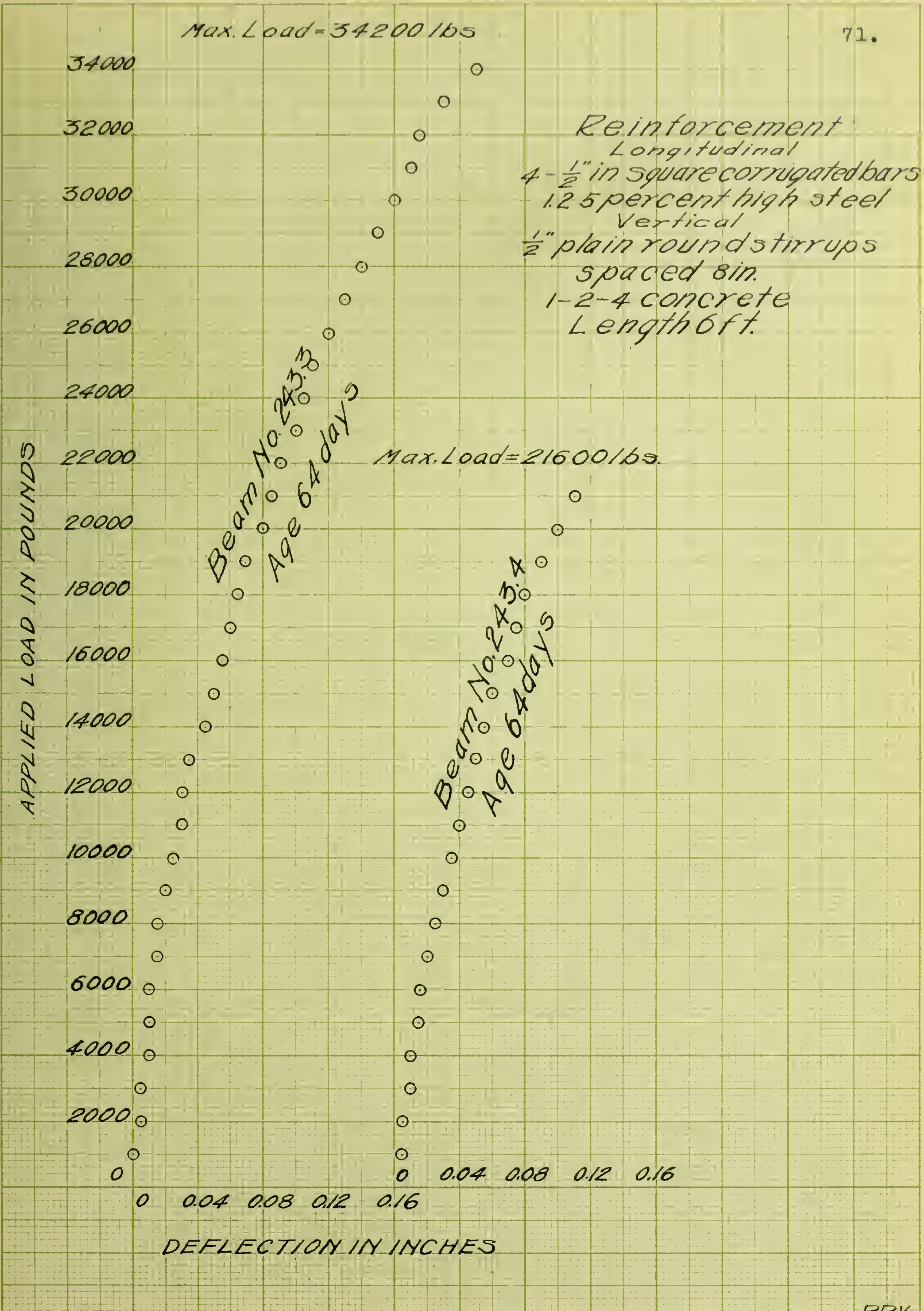

PERCENT OF DEPTH
50
60
70
80
90
NEUTRAL AXIS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
APPLIED LOAD IN POUNDS
APPLIED LOAD IN POUNDS
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Steel
Upper fiber
Deflection
Beam No. 253.1
4-3/4" square corrugted
high steel bars
2.81 percent steel
Maximum load=21300 lbs.
1-2-4 concrete
Length 12 ft.
DEFLECTION IN INCHES
0
0.10
0.20
0.30
0.40
0.50
0
.0002
.0004
.0006
.0008
.0010
.0012
DEFORMATION PER UNIT LENGTH
P.P.V.

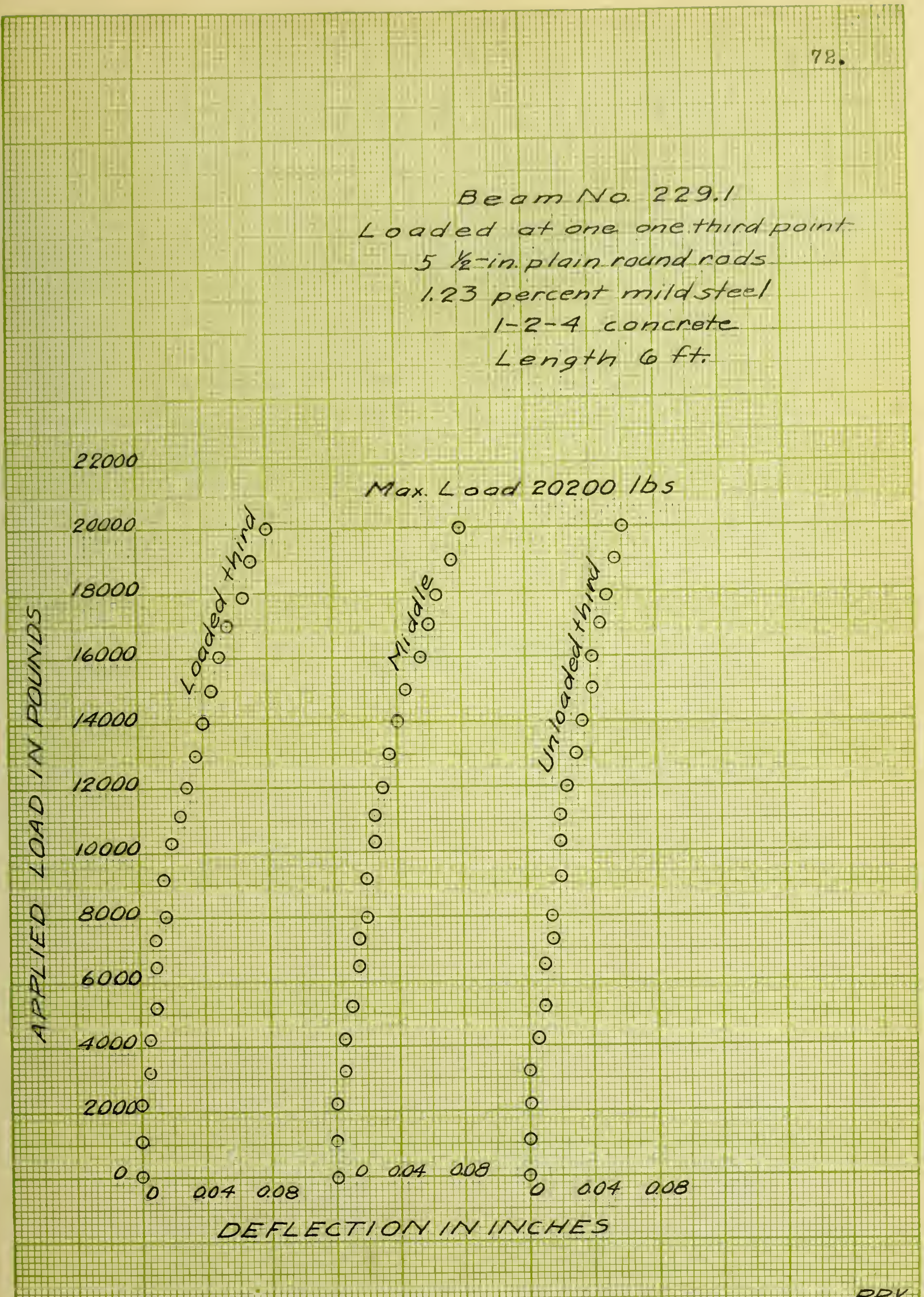

Beam No. 253.5
4-1/2" square corrugated bars
1.25 percent high steel
1-2-4 concrete
Maximum load=18500 lbs
Length 12 ft.
PERCENT OF DEPTH
40
50
60
NEUTRAL AXIS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
APPLIED LOAD IN POUNDS
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Steel
Upper fiber
Deflection
DEFLECTION IN INCHES
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
.0002
.0004
.0006
.0008
.0010
.0012
.0014
.0016
.0018
.0020
DEFORMATIONS PER UNIT LENGTH
P.P.V.


Max. Load=24500 lbs.
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
APPLIED LOAD IN POUNDS
0
0.04
0.08
0.12
0.16
DEFLECTION IN INCHES
Beam No. 253.6
4-1/2" square corrugated bars
1.25 percent high steel
1-2-4 concrete
Age 64 days
Length 6 ft
P.P.V.


Max. Load = 31100 lbs.
Reinforcement
Horizontal
3-3/4" plain round bars
1.66 percent mild
Vertical
1/2 plain round stirrups
spaced 5 in.
1-2-4 concrete
Length 6 ft.
Beam No. 22.13
Age 57 days
Max. Load = 21200 lbs.
Beam No. 22.14
Age 70 days
APPLIED LOAD IN POUNDS
32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.04
0.08
0.12
0.16
0
0.04
0.08
0.12
0.16
DEFLECTION IN INCHES
P.P.V.


Reinforcement
Horizontal
5-½ plain round rods
1.23 percent mild steel
Vertical
¼" plain round stirrips
spaced 3 in.
1-2-4 concrete
Length 6 ft.
Max. Load = 26200 lbs.
Max. Load = 24600 lbs.
Beam No. 223.2
Age 57 days
Beam No. 223.3
Age 70 days
APPLIED LOAD IN POUNDS
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
0 0.04 0.08 0.12 0.16
0 0.04 0.08 0.12 0.16 0.20 0.24 0.28 0.32
DEFLECTION IN INCHES
P.P.V.


Max. Load = 34200 lbs
Reinforcement
Longitudinal
4 - 1/2" in square corrugated bars
1.25 percent high steel
Vertical
1/2" plain round stirrups
spaced 8 in.
1-2-4 concrete
Length 6 ft.
Beam No. 243.3
Age 64 days
Max. Load = 21600 lbs.
Beam No. 243.4
Age 64 days
APPLIED LOAD IN POUNDS
34000
32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 0.04 0.08 0.12 0.16
0 0.04 0.08 0.12 0.16
DEFLECTION IN INCHES
P.P.V.


Beam No. 229.1
Loaded at one one third point
5 ½-in. plain round rods
1.23 percent mild steel
1-2-4 concrete
Length 6 ft.
Max. Load 20200 lbs
Loaded third
Middle
Unloaded third
APPLIED LOAD IN POUNDS
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.04
0.08
DEFLECTION IN INCHES
P.P.Y.

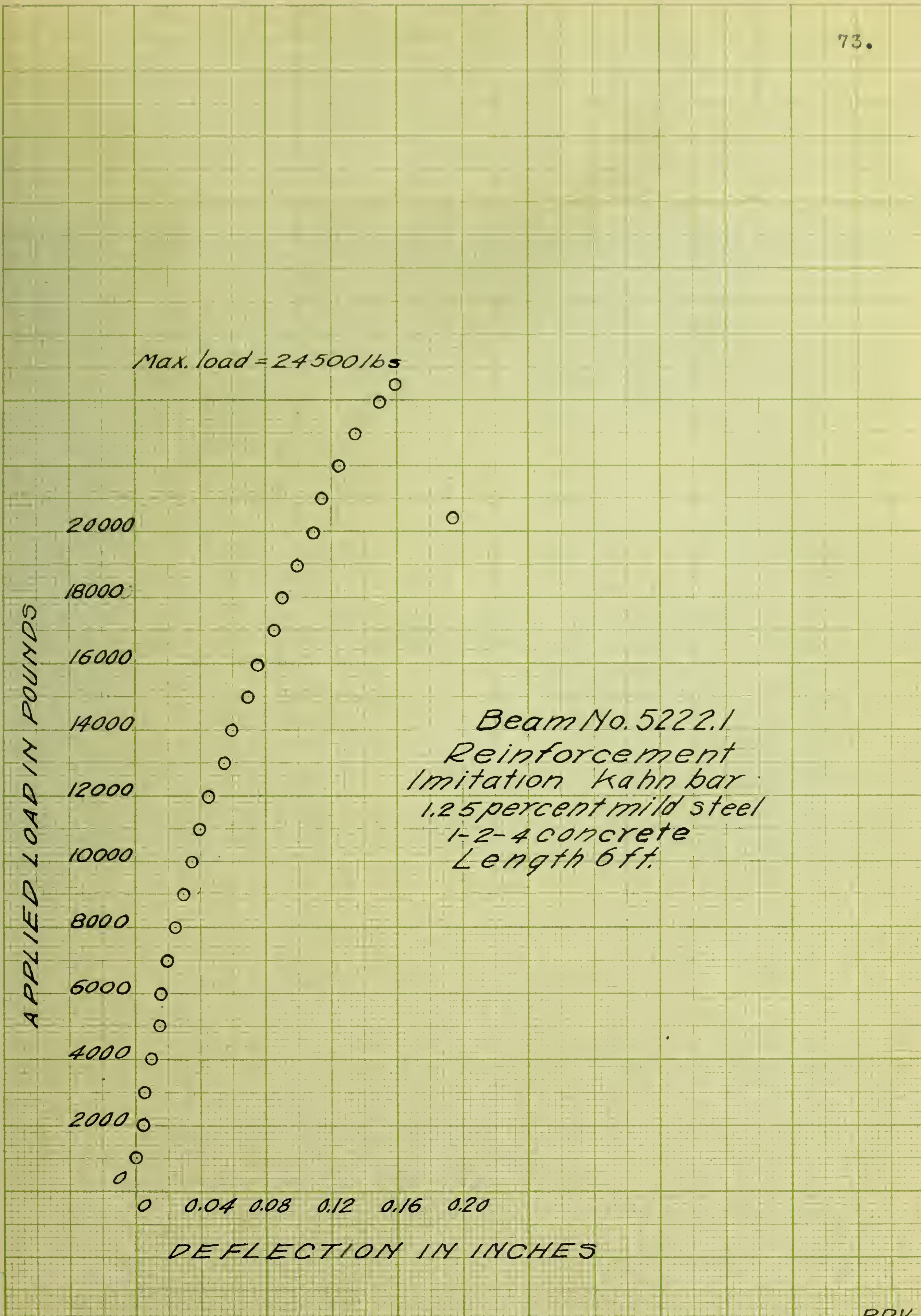

Max. load = 24500 lbs
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
APPLIED LOAD IN POUNDS
0
0.04
0.08
0.12
0.16
0.20
DEFLECTION IN INCHES
Beam No. 5222.1
Reinforcement
Imitation kahn bar
1.25 percent mild steel
1-2-4 concrete
Length 6 ft.
P.P.V.

PLATE IV.

Characteristic Failure of Class A.

Beam 213.3 Span 6 ft. Concrete 1-3-6
0.98 Per cent reinforcement.

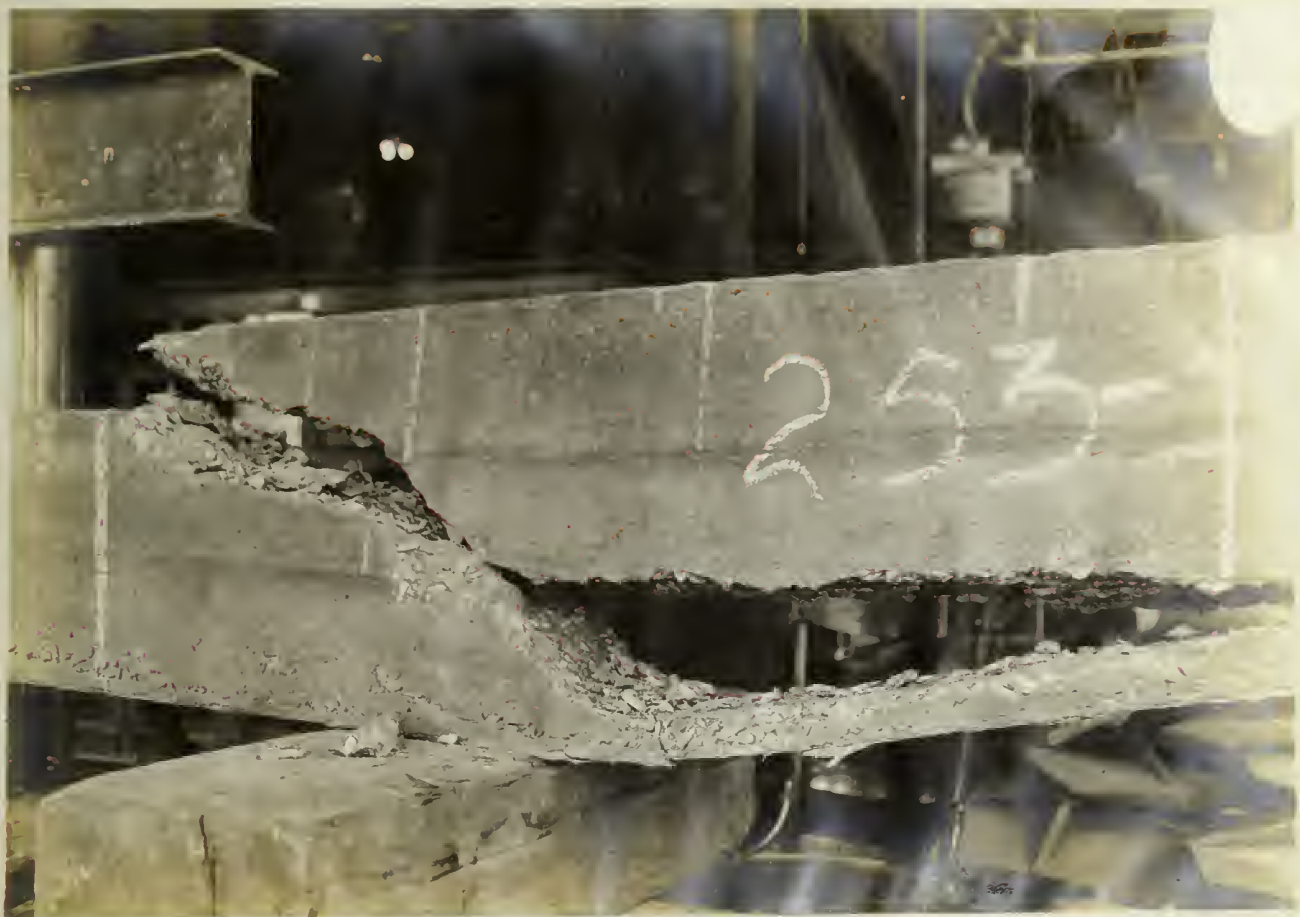


PLATE V.

Characteristic Failure of Class B.

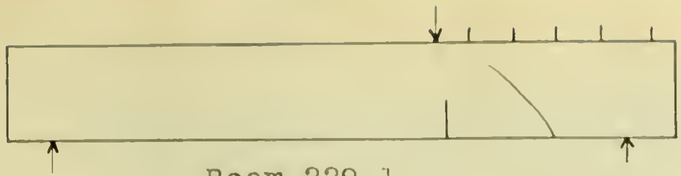
Beam 253.5 Span 12 ft. Concrete 1-2-4

1.25 Per cent reinforcement.

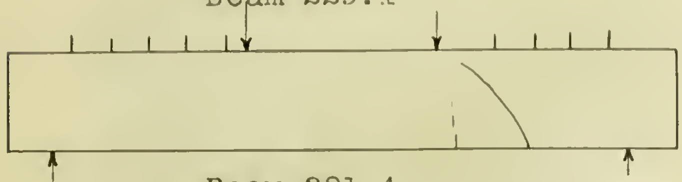
PLATE VI.

Beam 256.2 Span 12 ft. Concrete 1-2-4.

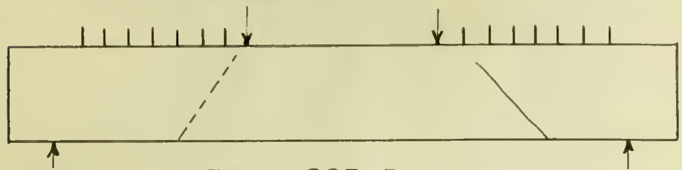
2.21 reinforcement.



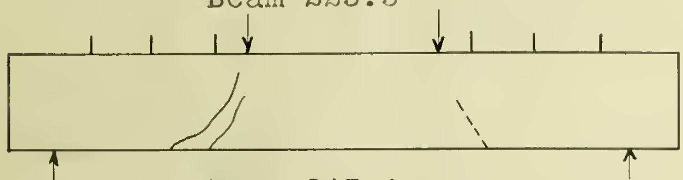
Beam 229.1



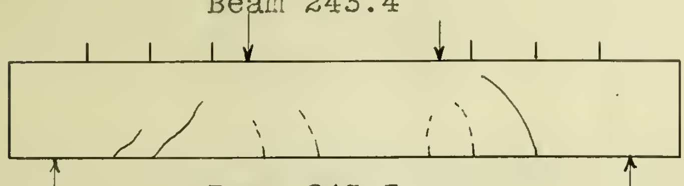
Beam 221.4



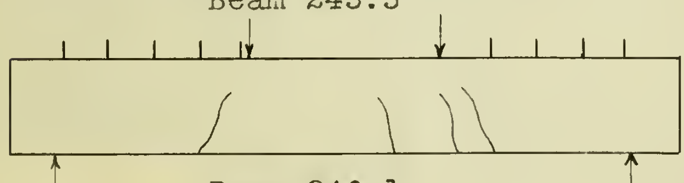
Beam 223.3



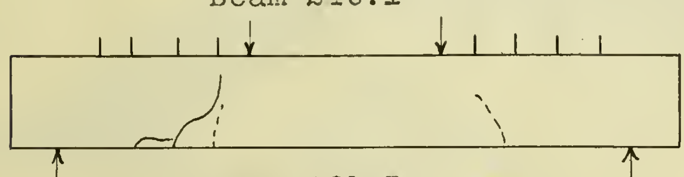
Beam 243.4



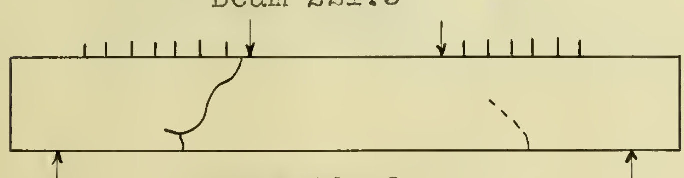
Beam 243.3



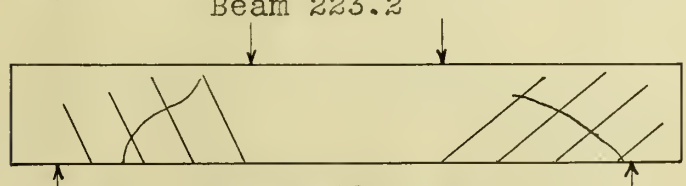
Beam 240.1



Beam 221.3



Beam 223.2



Beam 522.1

PLATE VII

Manner of Failure of Beams of Class C.

PLATE VIII.

Characteristic Failure of Class C.

Beam 221.3 Span 6 ft. Concrete 1-2-4.

1.66 Per cent reinforcement.

1/2-in. stirrups spaced 5 in.