1637

# T H E S I S

## TESTS ON REINFORCED CONCRETE BEAMS AND CULVERT SECTIONS

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## History

Reinforced concrete is a building material used in construction work, and consists of a skeleton work of metal embedded in a mass of concrete or cement mortar.

Iron rods have been used to tie together and strengthen masonry structures for hundreds of years. Cut stone and ruble masonry do not adapt themselves to the use of iron or steel to take care of the tensile strains, hence not until the advent of modern concrete do we find masonry structures having a metal reinforcement.

The first exhibition of reinforced concrete was at the World's Fair at Paris in 1855. The exhibit was a small row boat, reinforced with wire netting. F. J. Momir was the first man to take out patents covering the use of reinforced concrete. His countryman did not appreciate his discoveries and the Germans were the first to develop this form of construction.

## Object

In these tests an endeavor has been made to compare as nearly as possible the relative strength of beams reinforced with different kinds of reinforcing bars and the strength of the arch (both plain and reinforced) and box form of culverts.

## Materials

The cement used was the ordinary Atlas Portland cement purchased in the open market. The tensile strength of neat cement being 208# per. sq.in. at 7 days, and 394# per sq.in. at 28 days.

The compressive strength at 7 days was 1915# per sq. in. and at 28 days 3210# per sq. in.

For a mixture of one part cement to three parts sand we have a tensile strength of 72# at 7 days and 209# per sq. in. at 28 days. The compressive strength of this same mixture was 834.7# at 7 days and 1497.6# per sq. in. at 28 days.

The above results were obtained from tests on standard briquettes and are the averages of six tests on each set. The compressive tests were made on briquettes of the form of a cube the dimensions of which were 2 inches and thus leaving a surface of 4 inches for compressive tests. The tensile tests were made on standard tensile briquettes, the area of cross section being 1 sq. in.

These briquettes were made and placed in moist air for 24 hours and then placed in water and allowed to stand until the time of testing. By taking these precautions all tendencies toward too rapid setting and shrinking are eliminated. Four inch compression cubes were made with each set of beams and culverts. From these cubes the compressive strength of concrete was calculated in the tables.

Sand: The sand used was Kaw River sand, coarse and sharp, and free from all extraneous matter. It contained voids to the amount of 32.2%.

Body: The body of stone was Joplin grit from Joplin, Missouri, ranging in size from 1/8" to 1/2" and containing 40.8% voids.

Reinforcing: For reinforcing purposes, wrought iron round and square bars, Johnson corrugated bars, Kahn trussed bars, chain, and herringbone lath were used, the amount of reinforcing being that calculated by the beam theory on the following pages. The elastic limits of the metals were as follows; Kahn trussed bars 38400# per sq. in. Johnson bar 53000# per sq. in., Wrought iron bars (round) 43190# per sq. in., Wrought iron bars (square) 37200#.

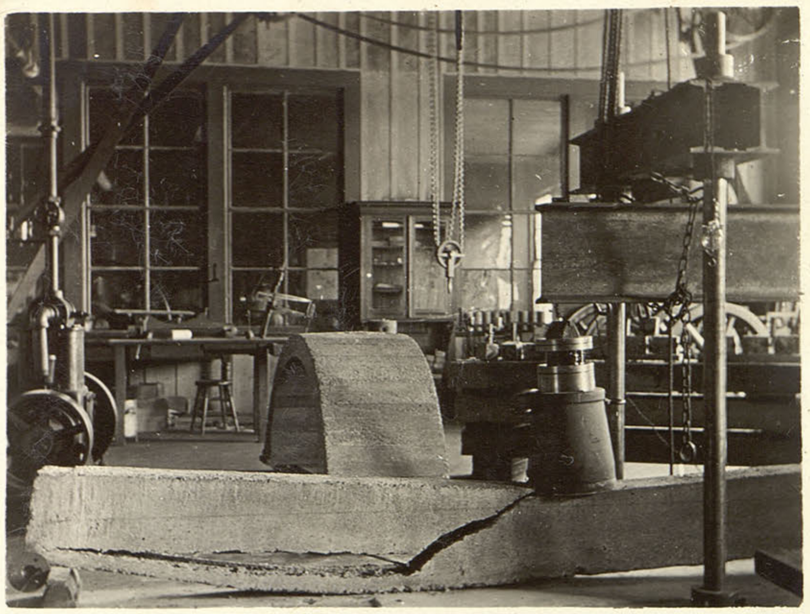
These values were found by testing the specimens in tension in the Riehle' testing machine. The herringbone lath was not tested.

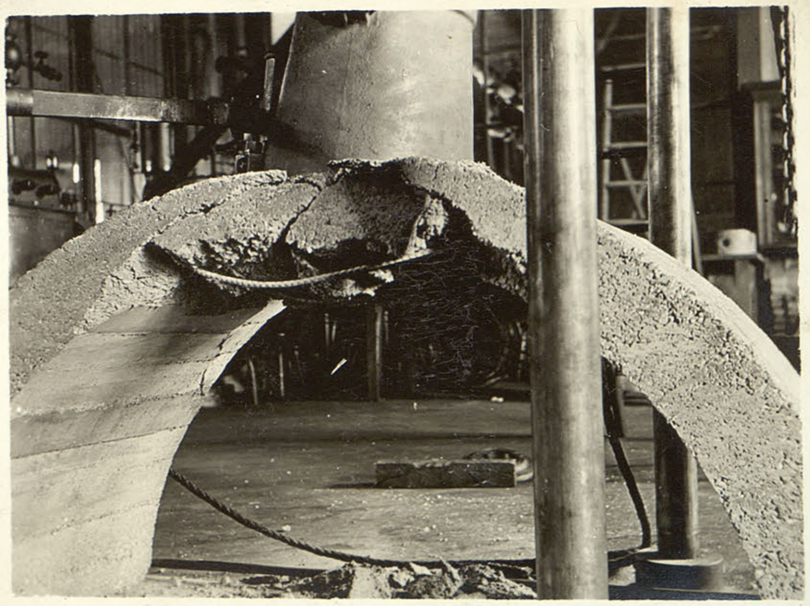
Mixtures and Forms: Two mixtures of concrete were used in making all of the test specimens, vis, 1 - 2 - 4 and 1 - 2 - 5, the results being tabulated on the following pages. In preparing the mortar, the sand and cement were carefully measured and then mixed together dry until the mixture was of a uniform color. Water was then added and again mixed until of a uniform consistency and the grit (previously dampened) added. The whole mass was then turned and so thoroughly mixed that each particle of grit was covered with the mixture of sand and cement. It was then ready for the forms.

Concrete should be so propoxtioned that the voids in the grit or rock should be entirely filled with the mixture of sand and cement and the voids in the sand should be filled with cement. When these conditions are fulfilled, we have what is called an ideal mixture.

All of the specimens were made in wooden forms that had previously been oiled to prevent the absorption of moisture from the concrete and also to prevent the warping of the forms themselves.

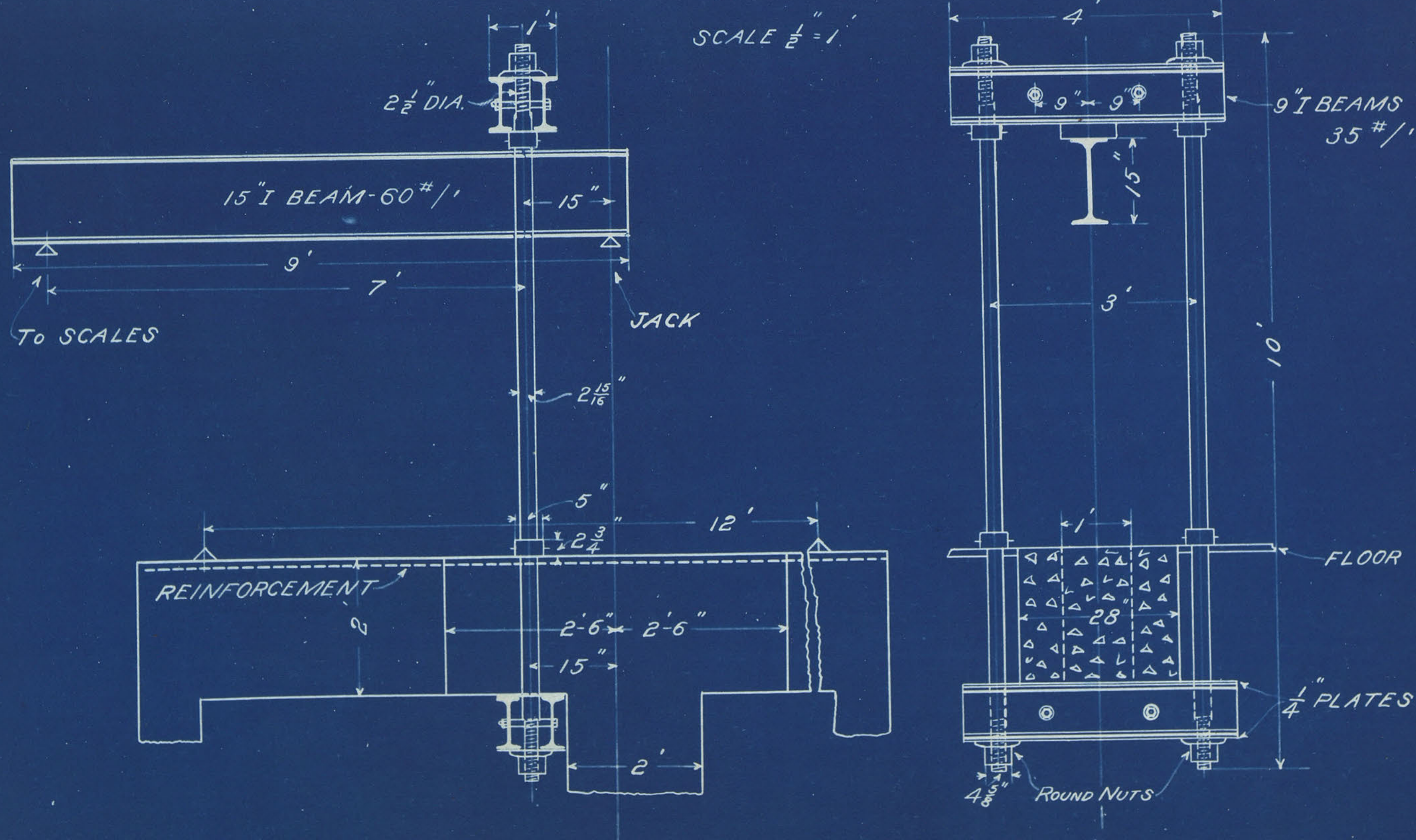

07





# TESTING YOKE

SCALE $\frac{1}{2}'' = 1'$



The concrete was made weter than in usual practice in order to secure compactness with little tamping, as too much tamping is liable to displace the reinforcing bars.

Testing Apparatus: The testing apparatüs is shown in the accompanying photograph and drawings. A reinforced beam was placed under the floor with its top at a level with the floor. This beam rests upon three supports. For a length of five feet at the centre this beam is twenty-eight inches wide forming a base for testing a two foot section of a four foot span culvert. Around this beam is placed a steel yoke and from this yoke is swung a lever consisting of a 15" I beam. One end of this beam is placed on the Riehle' machine and the other end upon a hydraulic jack of 100 tons capacity. The yoke acting as the fulcrum of the lever, we have a lever in the ratio of 5.6 to 1, i e, 5.6 pounds on short arm, will balance 1 pound on the long arm. Knowing this ratio, the loads on the beams can be measured by the Riehle' machine.

Tests: All of the large 8" x 12" - 14' beams were tested in the yoke with the hydraulic jack and lever attachment. The short 4" x 6" - 6' beams were tested in the Riehle' machine with the beam attachment. The span was 6 ft. with the load concentrated at the centre.

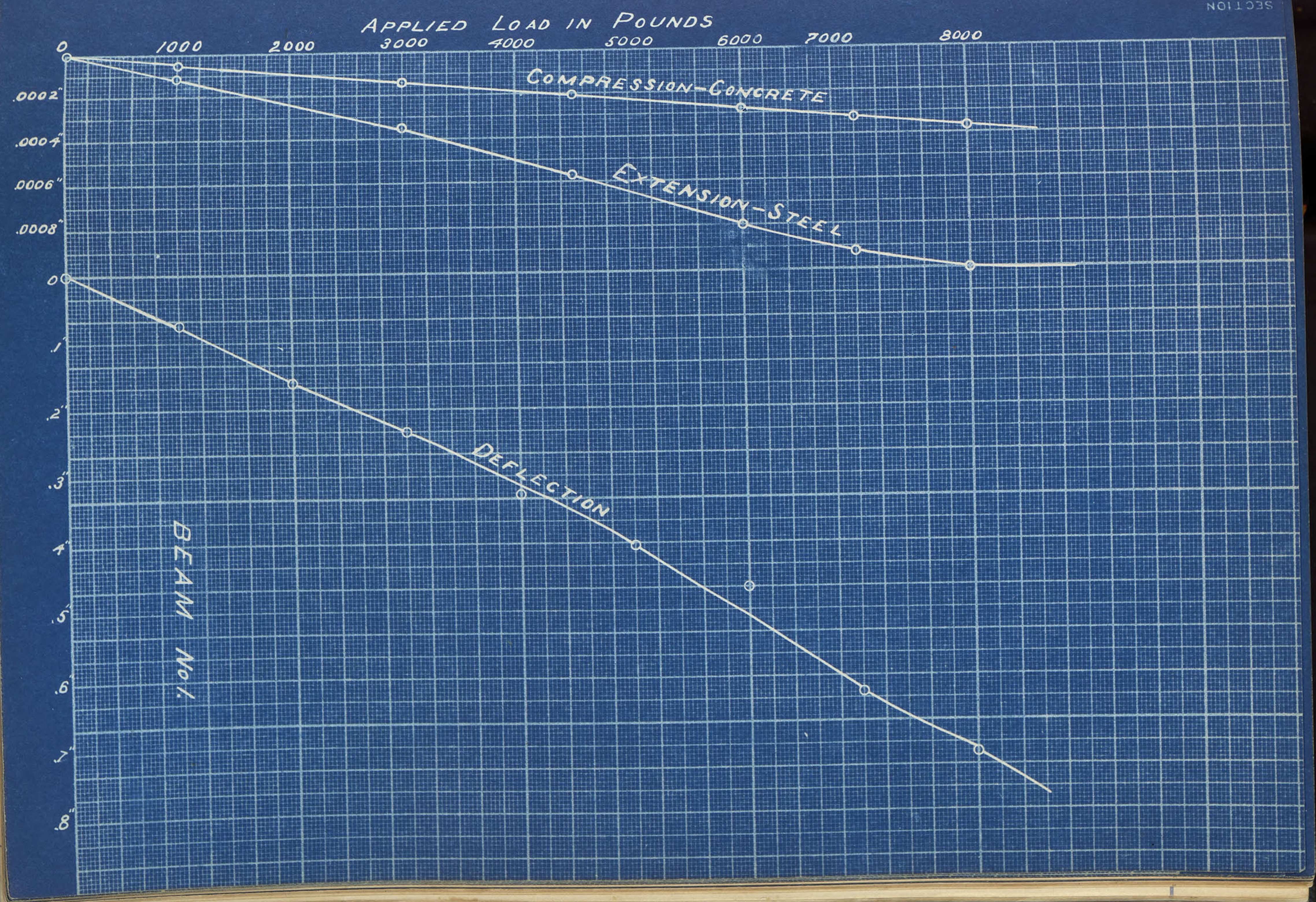
Deflections on the small beams were taken with a deflectometer, for each load as shown in the accompanying data. On the large beams the span was 12 ft. and load concentrated at the centre. The deflections were taken with a scale and pair of dividers. A wire was stretched along the centre of the beam and kept taut at the ends with weights. The scale was clamped on the beam near the centre and as the beam deflected, the readings were taken directly off the scale. As a check on these readings, a tack was driven into the beam and the distance from a punch mark on the tack to the wire was taken with a pair of dividers, for each load.

Neutral Axis. An attempt was made to note the variation of the position of the neutral axis on large beams. Perpendicular rows of tacks 2 ft. apart were driven in the green beams, the horizontal distance apart being two inches. As the load was applied, the top edge of the beam will shorten and the lower edge will lengthen. By taking readings on the several rows of tacks, we can note the distortions and variations of the neutral axis. The readings were taken for each load of 1000#. The results of the readings for the variation of the neutral axis were not accurate enough to warrant giving them here.

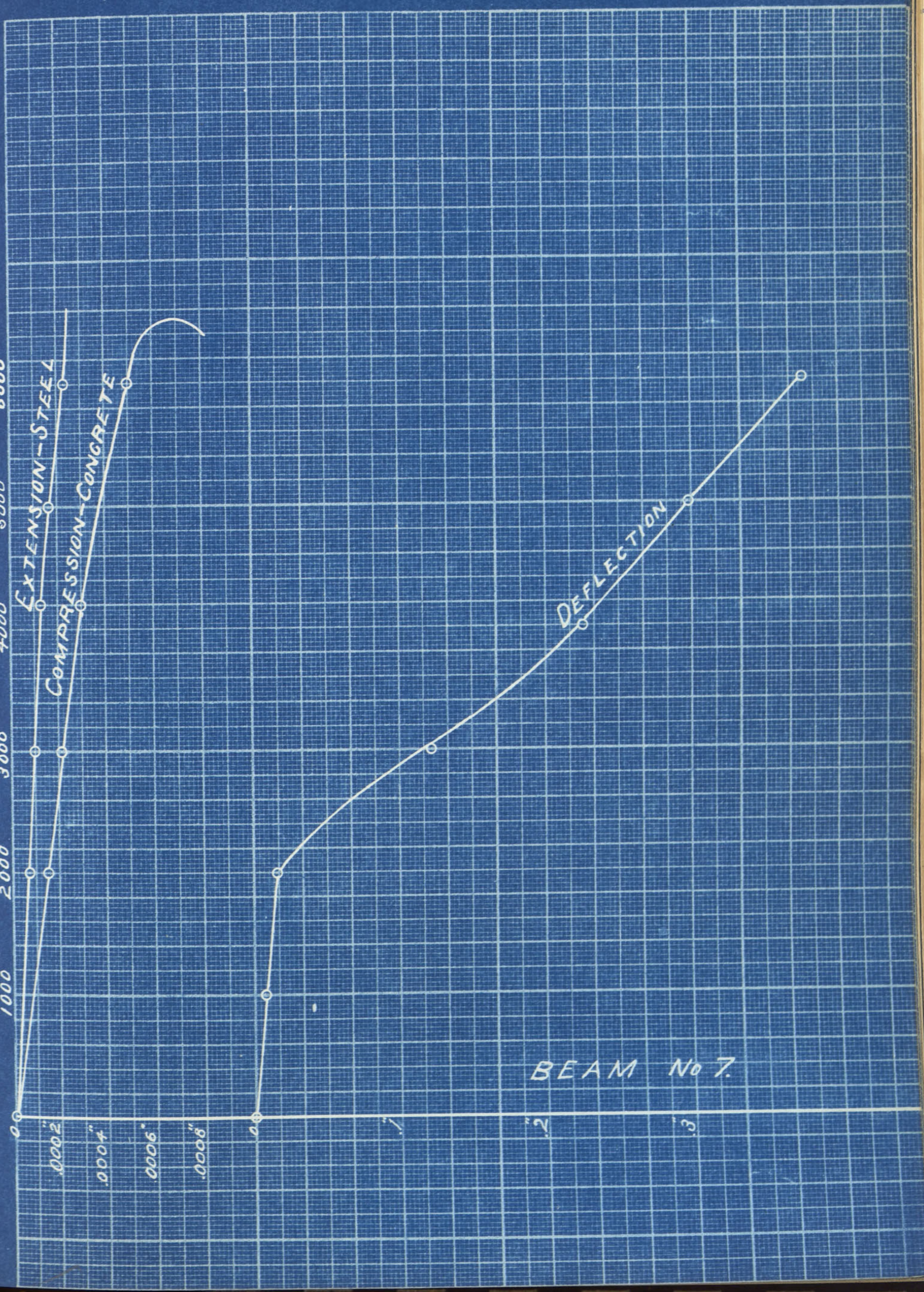
Curves: Curves showing deflection, extension of steel, and compression of concrete are shown on the following sheets for large beams No. 1, 7, and 14. The data for the elongation of the steel and compression of the concrete in the beams was obtained by taking the readings on the upper and lower row of tacks used in the neutral axis experiment. The upper row of tacks showed the compression of the concrete and the lower row the elongation of the steel for each load as taken.

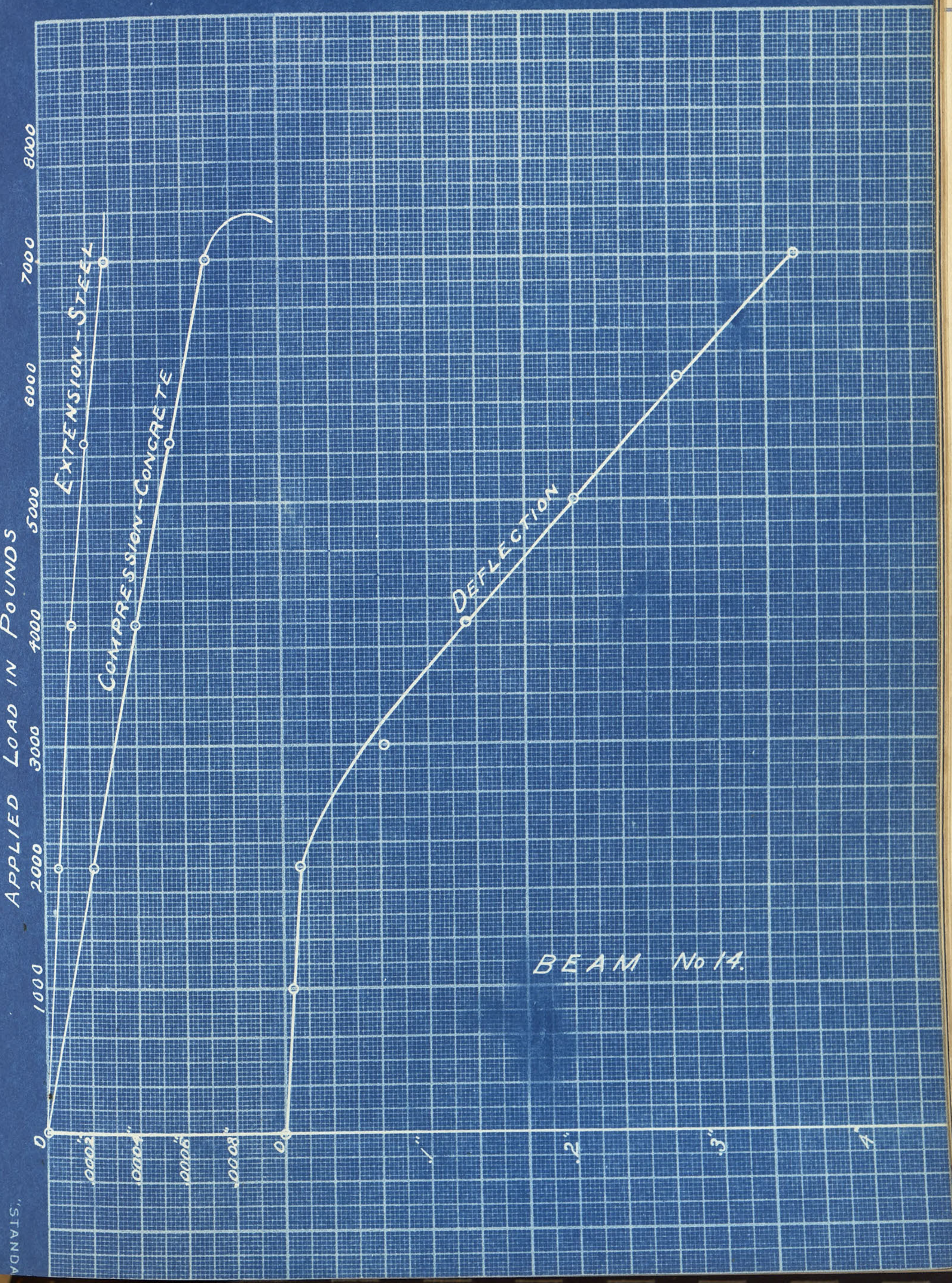
The other curves are typical deflection curves of the small 4" x 6" beams for each sort of reinforcement used.

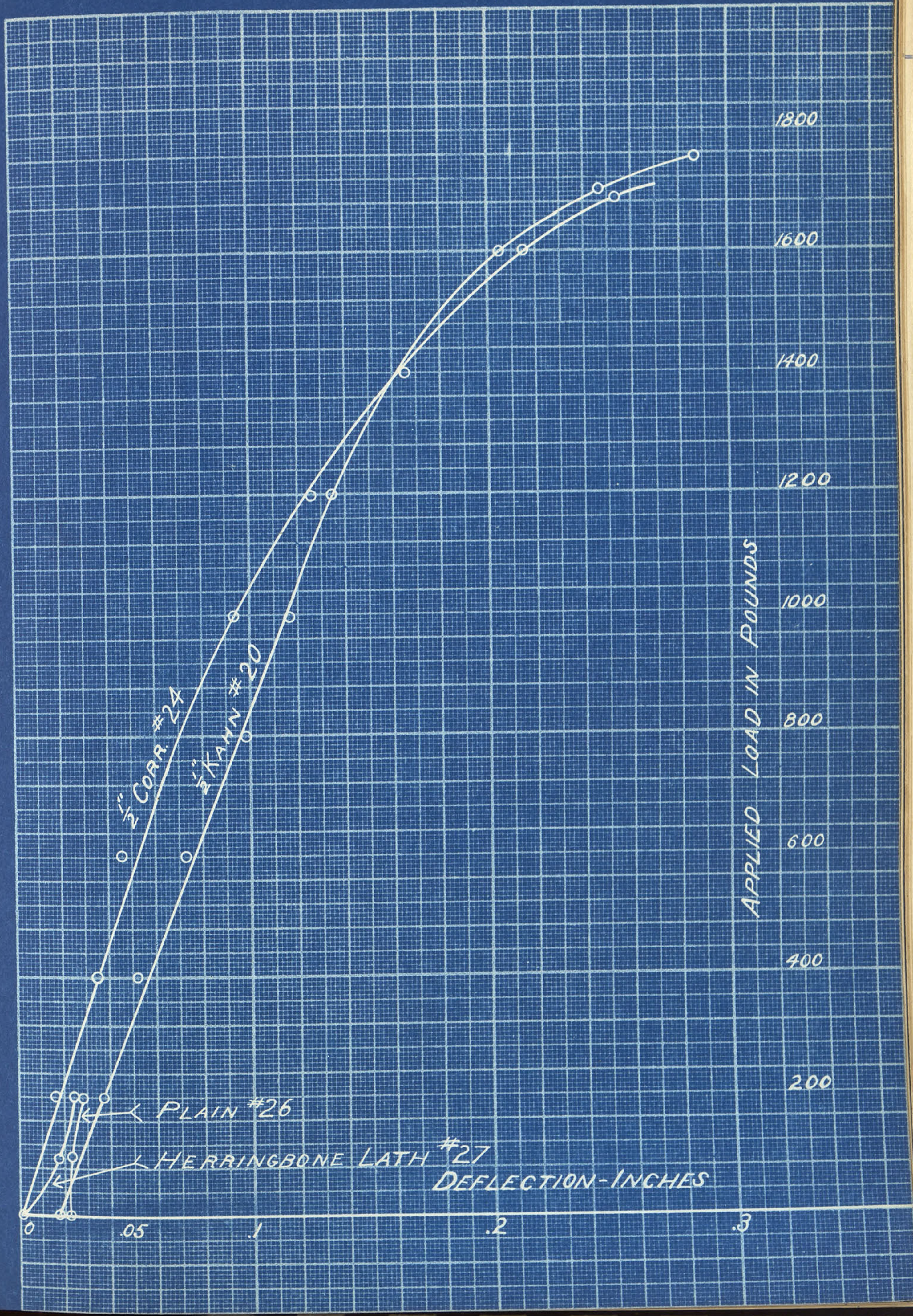
Explanation of Tables: On the pages containing the beam data, all items are self explanatory with the exception of



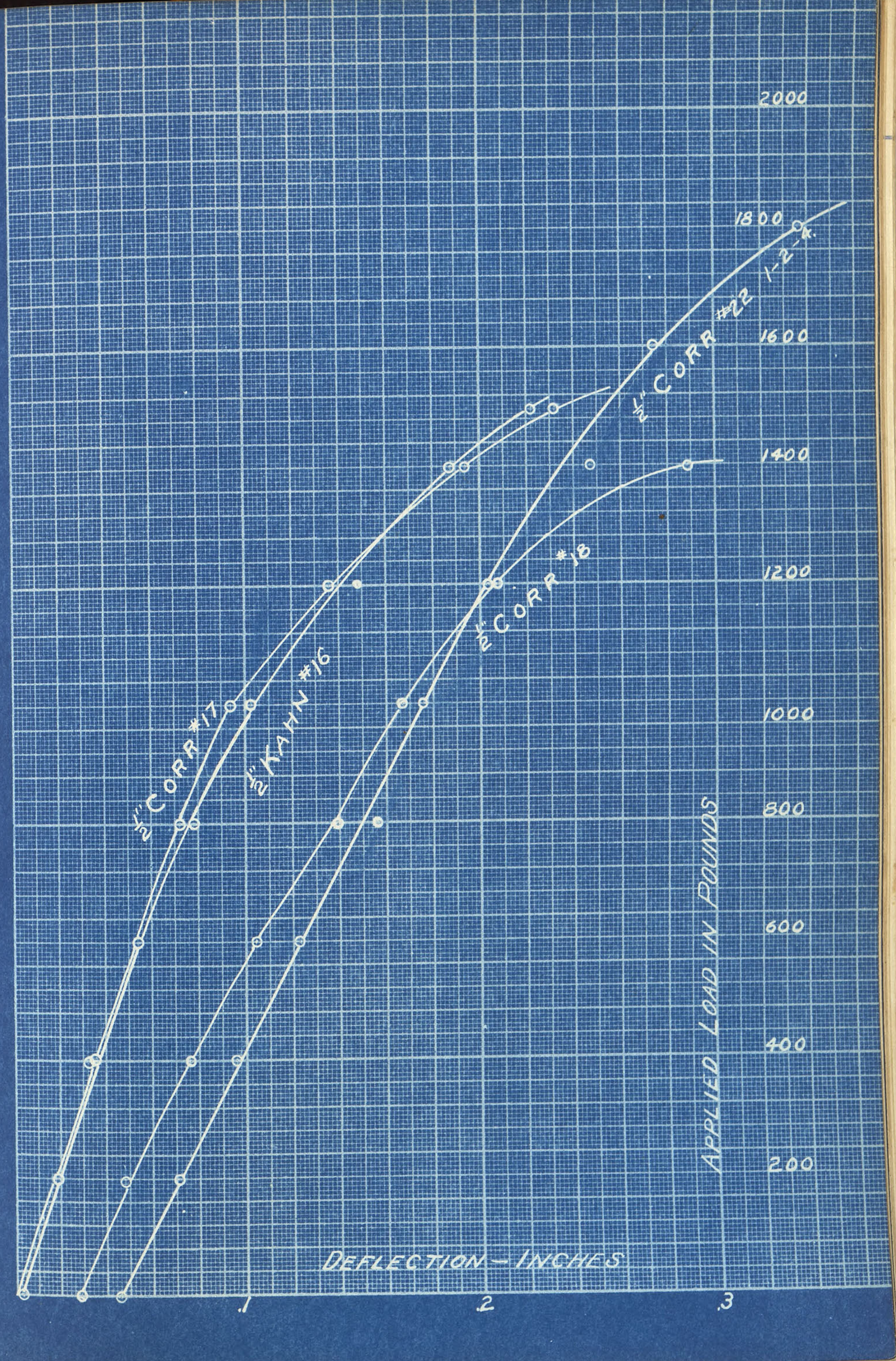
APPLIED LOAD IN POUNDS
0
1000
2000
3000
4000
5000
6000
7000
8000
.0002"
.0004"
.0006"
.0008"
0
.1"
.2"
.3"
.4"
.5"
.6"
.7"
.8"
COMPRESSION-CONCRETE
EXTENSION-STEEL
DEFLECTION
BEAM No1.


APPLIED LOAD IN POUNDS
0
1000
2000
3000
4000
5000
6000
EXTENSION-STEEL
COMPRESSION-CONCRETE
DEFLECTION
BEAM No 7.
.0002"
.0004"
.0006"
.0008"
.1"
.2"
.3"

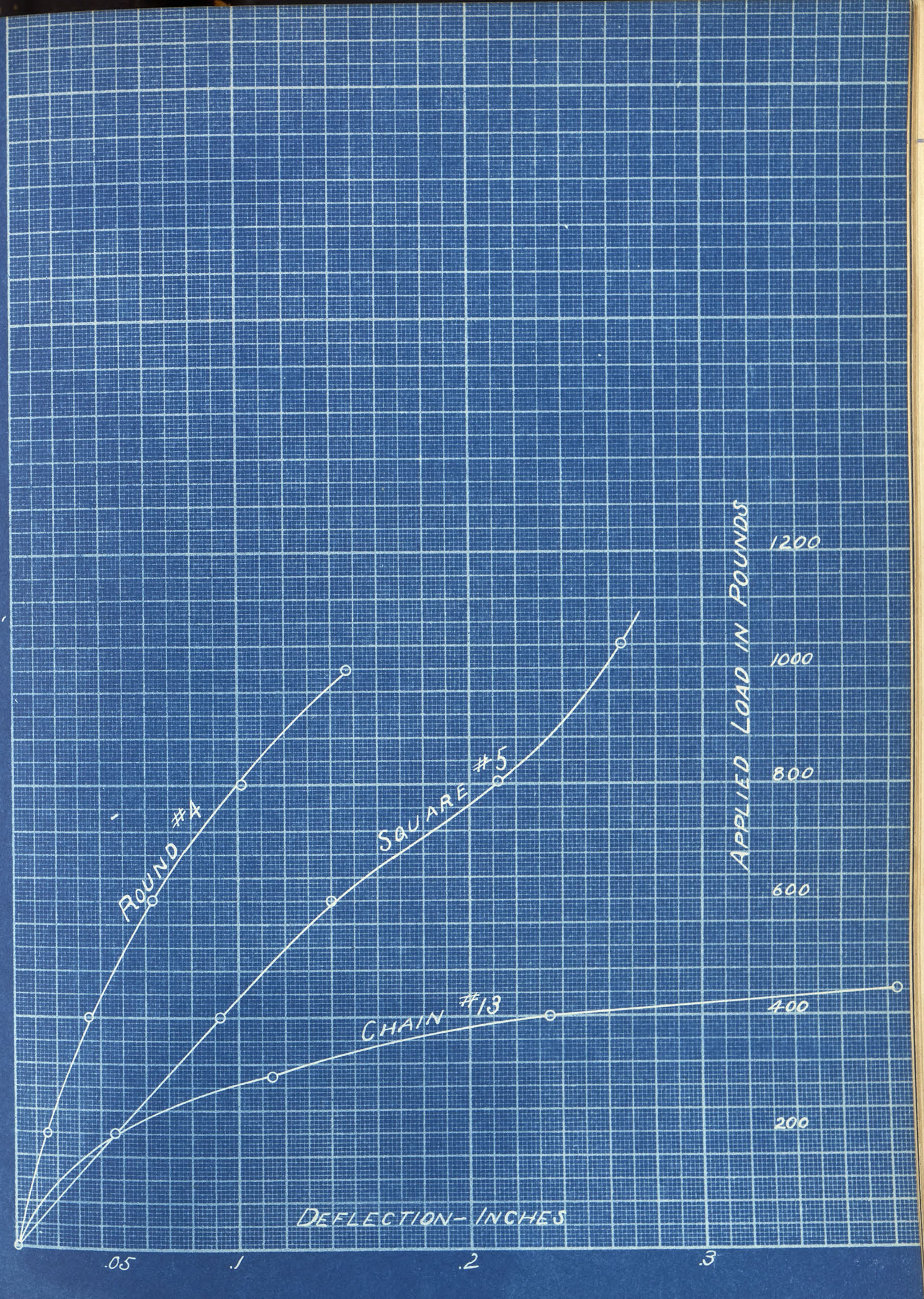

APPLIED LOAD IN POUNDS
0
1000
2000
3000
4000
5000
6000
7000
8000
EXTENSION-STEEL
COMPRESSION-CONCRETE
DEFLECTION
BEAM No 14.
.0002"
.0004"
.0006"
.0008"
0
1"
2"
3"
4"



1800
1600
1400
1200
1000
800
600
400
200
APPLIED LOAD IN POUNDS
1/2" CORR. #24
1/2" KAHN #20
PLAIN #26
HERRINGBONE LATH #27
DEFLECTION-INCHES
0
.05
.1
.2
.3



½" CORR #17
½" KAHN #16
½" CORR #18
½" CORR #22 1-2-4.
2000
1800
1600
1400
1200
1000
800
600
400
200
APPLIED LOAD IN POUNDS
DEFLECTION - INCHES
.1
.2
.3



APPLIED LOAD IN POUNDS
1200
1000
800
600
400
200
ROUND #4
SQUARE #5
CHAIN #13
DEFLECTION- INCHES
.05
.1
.2
.3

the columns containing the allowable loads, modulus of rupture, and bending moments.

The allowable load is that load that in actual practice if placed on a beam will not cause a deflection of more than 1/360 of the span.

The modulus of rupture is defined as the strain at the instant of rupture upon a unit of section which is most remote from the neutral axis on the side which first ruptures. It is = to $\frac{My}{I}$ where $M = \frac{WL}{4}$. $\frac{WL}{4}$ = the bending moment for beams with a concentrated load at the centre.

Computation of % of reinforcement.

Beam No. 17 1/2" corrugated bar

Beam No. 26 Plain with a load of 200# gave a deflection of .007". Formulae by

$$P = \frac{1}{2\left(\frac{f_s}{f_c}\right)\left(1 + \frac{f_s}{rf_c}\right)}$$

Where $P$ = % of steel

$f_s$ = stress of steel in tension

$f_c$ = " " concrete in compression

$r$ = ratio of modulus of elasticity of steel to modulus of elasticity of concrete.

$f_s = 52000$

$f_c = 695.6$

$r = 9.4$

$$P = \frac{1}{2\left(\frac{52000}{695.6}\right)\left(1 + \frac{52000}{9.4 \times 695.6}\right)}$$

$$P = \frac{1}{2 \times 74.74 \times 8.95} = .00074$$

or .074%

Beam No. 26 plain. 200# load gives deflection of .007".

$$\text{Deflection} = \frac{WL^3}{48EI}$$

$$W = 200\#$$

$$L = 72"$$

$$I = \frac{BH^3}{12}$$

$$= \frac{200 \times 72 \times 72 \times 72 \times 12}{48 \times E \times 4 \times 6 \times 6 \times 6}$$

$$= 3,085,000$$

Culvert Data

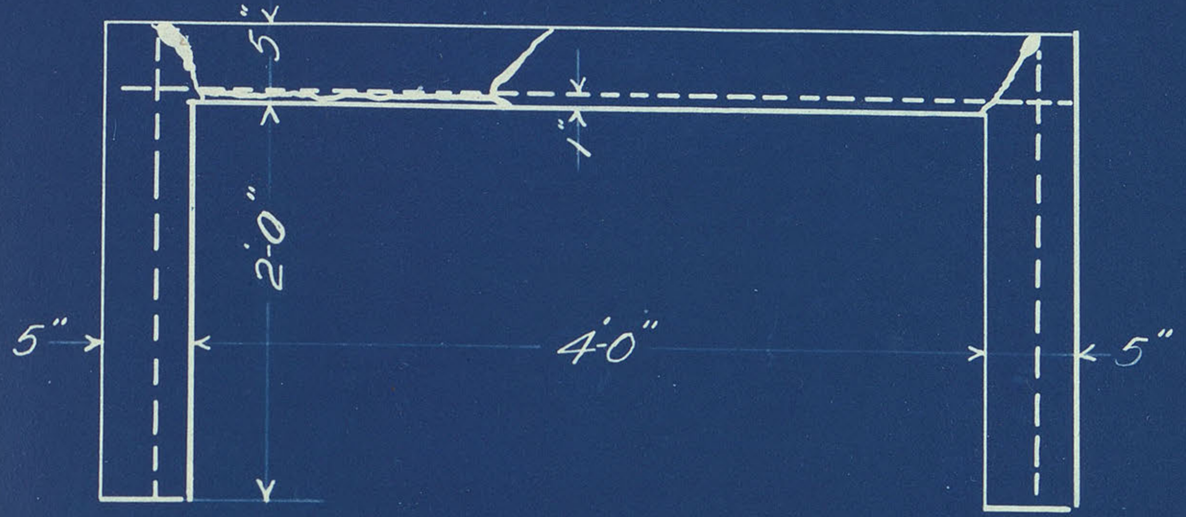
| Culvert | Load | Age | Reinforcement | Area | % | Wt. | Area of opening |
|---|---|---|---|---|---|---|---|
| arch | 23920 | 45 | 8 - 1/4" corr. | .48 | .4 | 874# | 6.28 sq. ft. |
| box | 10500 | 45 | 3 - 1/2" " 14-1/4" at ea. end | .75 | .625 | 1052# | 8 " " |
| plain | 6650 | 37 | plain | | | 865# | 6.28 |

The culvert sections were two feet wide. The box section was four feet from centre to centre of supports and the arches were of two feet radius. To prevent end thrust and to make the action similar to actual conditions as possible, a yoke was made which held the ends together.

The weight of the box section was slightly greater than the arch and the opening was 1.27 times larger. There was 1.5 times as much steel in the box as in the arch section and the arch stood over twice as much load.

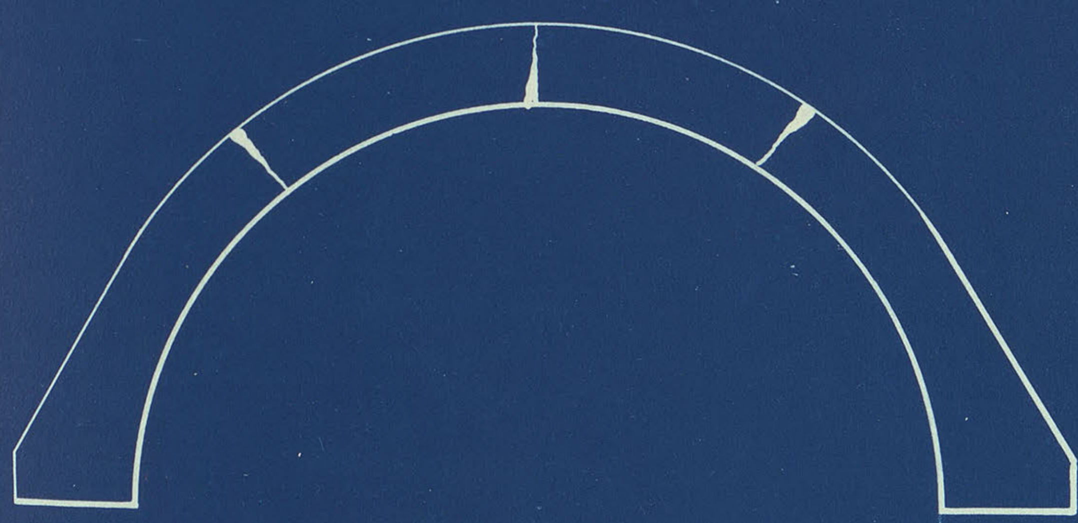
The box section failed by breaking at the corners

## Box Culvert Section



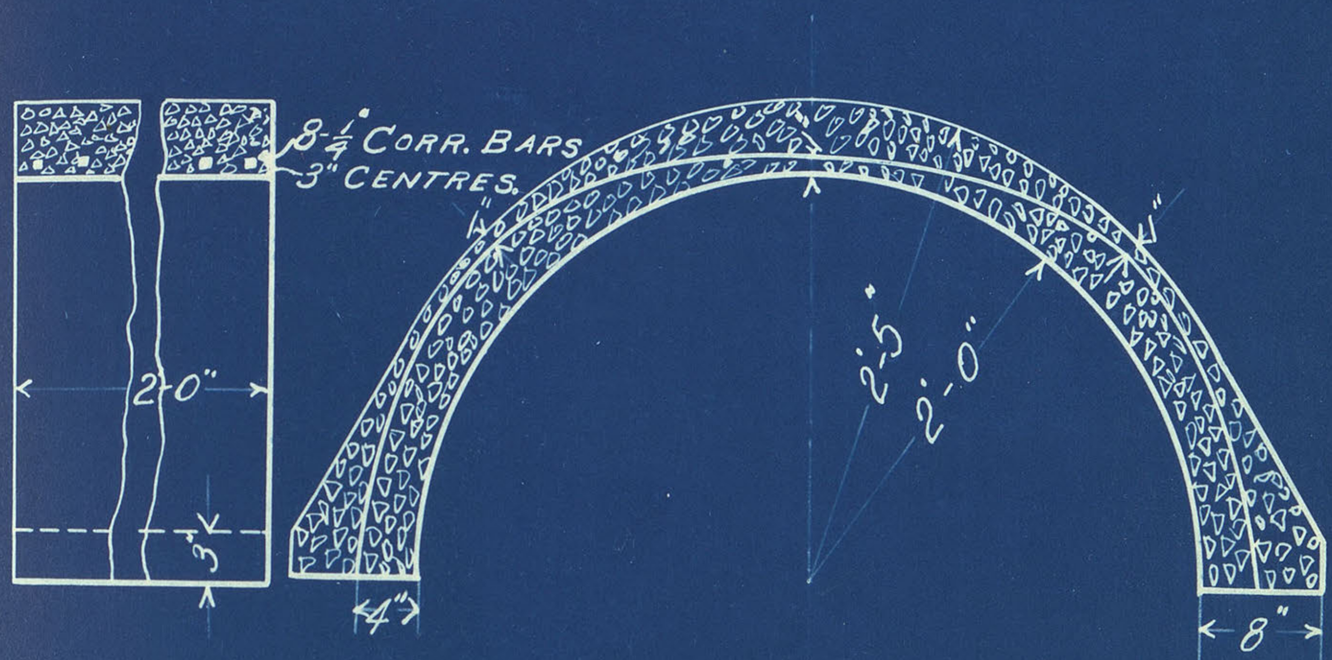

3-½" Corr. Bars 8" Centres.
Breaking Load 10500.#

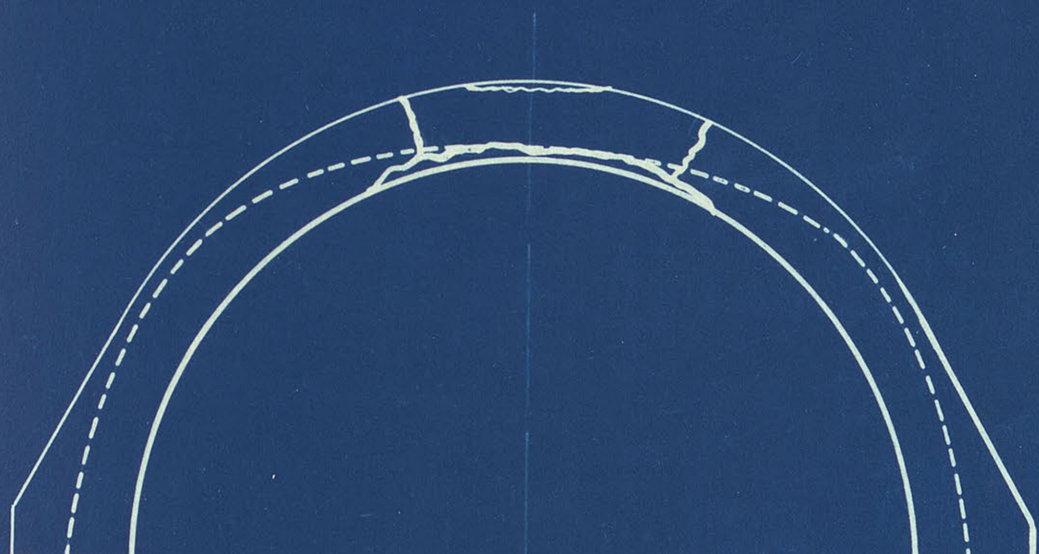
## Plain Arch



Breaking Load 6650.#

# ARCH SECTIONS.



MODE OF FRACTURE.
BREAKING LOAD 23920.#

first, the concrete failing in tension and then in shearing at the middle. The reinforced arch failed by first pushing the concrete off from under the reinforcement and then the concrete on top failed in shear.

The plain arch broke in the middle and at a point half way around the arch on each side. The failure was in tension in all cases. In the middle the tension came underneath and on the haunches it came on top. This gives a good idea as to how the reinforcement should be placed. The reinforced arch was made very nearly correct as the bars were one inch from the bottom in the middle of the arch and one inch from the top at the haunches.

In general the reinforced arch is the most satisfactory. It takes less concrete for a given span, and much less steel for a given strength, than the box section.

Deflection Readings

On Small 4" x 6" x 6' - 0 Concrete Beams

No. 3.

| Load | Def. | Remarks |
|---|---|---|
| 000 | 000 | |
| 100 | 004 | Reinforcement 1 - 1/2" dia. |
| 200 | 012 | round bar |
| 300 | .019 | Failed by shearing along |
| 400 | 027 | axis of rod |
| 500 | 032 | |
| 600 | 048 | |
| 700 | 081 | |
| 800 | .092 | |
| 900 | .108 | |
| 1000 | .129 | |
| 1100 | .153 | |
| 1200 | .184 | |
| 1300 | .127 | |
| 1400 | | |

No. 4.

| Load | Def. | Remarks |
|---|---|---|
| 000# | .000" | |
| 100 | .004 | Reinforcement 1 - 1/2" |
| 200 | .015 | plain rod |
| 300 | .024 | |
| 400 | .034 | Failed by shearing and |
| 500 | .047 | splitting along axis of bar |
| 600 | .062 | |
| 700 | .083 | |
| 800 | .102 | |
| 900 | .121 | |
| 1000 | .146 | |

No. 11. Remarks

| Load | Def. | Remarks |
|---|---|---|
| .000 | .000 | |
| 100 | .018 | Reinforcement 1 - 1/2" |
| 200 | .011 | corrugated bar |
| 300 | .024 | Failed by crushing and shear- |
| 400 | .031 | ing |
| 500 | .038 | |
| 600 | .056 | |
| 700 | .083 | |
| 800 | .182 | Elastic limit |

Beam No. 5.

| Load | Def. | Remarks |
|---|---|---|
| 000# | .004" | Reinforcement 1 - 1/2" |
| 100# | .031" | plain square bar. |
| 200# | .047" | Failure by slipping of |
| 300# | .070" | bar and also by splitting |
| 450# | .092" | along axis of bar |
| 500# | .113" | |
| 600# | .140" | |
| 700# | .173" | |
| 800# | .211" | |
| 900# | .228" | |
| 1000 | .264 | |

Beam 26.

| Load | Def. | Remarks |
|---|---|---|
| 000# | .020 | No reinforcement |
| 100# | .021 | Failure by breaking in |
| 200# | .027 | two very suddenly. |

No. 13

| Load | Def. | Remarks |
|---|---|---|
| 000# | 000 | Reinforcement of chain |
| 100 | .014 | Failed by tension of |
| 200 | .046 | concrete under chain |
| 300 | .113 | also by shearing and |
| 400 | .234 | splitting |
| 450 | .384 | |
| 50 | .430 | |

Beam No. 6.

| Load | Def. | Remarks |
|---|---|---|
| 000# | .016" | Plain 1/2" square bar |
| 100 | .024" | for reinforcing |
| 200 | .047" | |
| 300 | .077" | Failure by shearing and |
| 400 | .101 | also slipping of rod in |
| 500 | .128 | concrete |
| 600 | .157 | |
| 700 | .194 | |
| 800 | .235 | |
| 900 | 342 | |

Beams No. 8 and 9, were plain beams and broke in handling.

Beam 10.

| Load | Def. | Remarks |
|---|---|---|
| 50# | .000 | Failure by compression at centre. |
| 150 | .010 | |
| 250 | .020 | No shearing whatever |
| 350 | .05 | |
| 450 | .064 | |
| 550 | .088 | |
| 650 | .118 | |
| 750 | .171 | |
| 850 | .369 | |

Beam 12.

| Load | Def. | Remarks |
|---|---|---|
| 55# | .000 | Failure along chain and |
| 150 | .030 | parallel to it |
| 250 | .184 | Reinforcement of chain |

Beam No. 2.

| Load | Def. | Remarks |
|---|---|---|
| 50# | .020" | Failure by breaking in two |
| 150 | .040 | pieces |
| 250 | .078 | |
| 350 | 117 | Herringbone lath reinforcement. Breaking load. |
| 400 | | |

No. 15.

| Load | Def. | Remarks |
|---|---|---|
| 000# | 001" | Reinforcement 1 - 1/2" |
| 100 | 004 | Kahn bar |
| 200 | .018 | |
| 300 | .027 | Failed by crushing on |
| 400 | .036 | compression side of beam. |
| 500 | .050 | |
| 600 | .065 | |
| 700 | .083 | |
| 800 | .098 | |
| 900 | .129 | |
| 1000 | .149 | |
| 1100 | .168 | |
| 1200 | .204 | |
| 1300 | 343 | |

No. 16.

| Load | Def. | Remarks |
|---|---|---|
| 000 | 003 | 1 - 1/2" Kahn bar for |
| 100 | .012 | reinforcement |
| 200 | .018 | Failed by crushing |
| 300 | .025 | |
| 400 | .033 | |
| 500 | 045 | |
| 600 | 054 | |
| 700 | 065 | |
| 800 | 078 | |
| 900 | 087 | |
| 1000 | .103 | |
| 1100 | .118 | |
| 1200 | .149 | |
| 1400 | .188 | |
| 1500 | .222 | |

No. 17.

| Load | Def. | Remarks |
|---|---|---|
| 000 | .000 | Reinforcement 1 - 1/2" |
| 100 | .009 | corrugated bar |
| 200 | .019 | Failed by splitting |
| 300 | .025 | along axis of rod |
| 400 | .035 | |
| 500 | .045 | |
| 600 | .054 | |
| 700 | .063 | |
| 800 | .073 | |
| 900 | .084 | |
| 1000 | .094 | |
| 1100 | .110 | |
| 1200 | .113 | |
| 1300 | .167 | |
| 1400 | .194 | |
| 1500 | .232 | |

Beam No. 18.

| Load | Def. | Remarks |
|---|---|---|
| 0# | .029" | Reinforced with 2 - 1/3" corrugated bars Failure occured by shearing and splitting along and parallel to reinforcing bars |
| 100 | .039 | |
| 200 | .048 | |
| 300 | .063 | |
| 350 | .070 | |
| 400 | .076 | |
| 450 | .082 | |
| 500 | .090 | |
| 550 | .097 | |
| 600 | .104 | |
| 650 | .111 | |
| 700 | .119 | |
| 750 | .126 | |
| 800 | .144 | |
| 900 | .155 | |
| 950 | .166 | |
| 1000 | .167 | |
| 1050 | .175 | |
| 1100 | .182 | |
| 1200 | .207 | |
| 1300 | .235 | |
| 1350 | .260 | |
| 1400 | .289 | Elastic limit. |

Beam No. 19.

| Load | Def. | Remarks |
|---|---|---|
| 000 | 000 | Mixture 1 - 2 - 4 2 - 5/16" sq. bars for reinforcement |
| 100 | .017 | |
| 200 | .024 | |
| 300 | .033 | |
| 400 | .041 | Failed by splitting along axis of bars |
| 500 | .050 | |
| 600 | .056 | |
| 700 | .075 | |
| 800 | 101 | |
| 900 | .112 | |
| 1000 | .127 | |
| 1100 | .140 | |
| 1200 | .158 | |
| 1300 | .190 | |
| 1400 | .210 | |
| 1500 | 225 | |
| 1600 | .252 | |
| 1700 | .288 | |

No. 20

| Load | Def. | Remarks |
|---|---|---|
| 000 | 014 | 1 - 1/2" Kahn bar for |
| 100 | 020 | reinforcement |
| 200 | 035 | Mixture 1 - 2 - 4 |
| 300 | .037 | Failed by crushing of |
| 400 | .050 | concrete |
| 500 | .060 | |
| 600 | .070 | |
| 700 | .081 | |
| 800 | .096 | |
| 900 | .107 | |
| 1000 | .115 | |
| 1100 | .120 | |
| 1200 | .134 | |
| 1300 | .146 | |
| 1400 | .163 | |
| 1500 | .184 | |
| 1600 | .205 | |
| 1700 | .246 | |
| 1750 | .285 | |

No. 21.

| Load | Def. | Remarks |
|---|---|---|
| 000 | 028 | Mixture 1 - 2 - 4 |
| 100 | 033 | Reinforcement 1 - 5/8" |
| 200 | 034 | round bar |
| 300 | 055 | Failure by splitting |
| 400 | 061 | along axis of bar |
| 500 | 071 | |
| 600 | 076 | |
| 700 | 097 | |
| 800 | .111 | |
| 900 | .128 | |
| 1000 | .139 | |
| 1100 | .160 | |
| 1200 | .189 | |
| 1300 | .210 | |
| 1400 | .277 | |

No. 22.

| Load | Def. | Remarks |
|---|---|---|
| 000# | .046" | |
| 100 | .057 | Beam 1 - 2 - 4 mixture |
| 200 | .071 | Failure by shearing and |
| 300 | .082 | splitting along and |
| 400 | .096 | parallel to reinforcing |
| 500 | .110 | bars |
| 600 | .123 | |
| 700 | .137 | Reinforcing: 1 - 1/2" |
| 800 | .156 | corrugated bar |
| 850 | .164 | |
| 900 | .170 | |
| 1000 | .178 | |
| 1100 | .188 | |
| 1200 | .203 | |
| 1250 | .212 | |
| 1300 | .221 | |
| 1350 | .236 | |
| 1400 | .247 | |
| 1450 | .253 | |
| 1500 | .259 | |
| 1550 | .267 | |
| 1600 | .275 | |
| 1650 | .287 | |
| 1700 | .299 | |
| 1750 | .312 | |
| 1800 | .337 | |

Beam No. 27.

| Load | Def. | Remarks |
|---|---|---|
| 000 | 000 | Reinforcement, Herring- |
| 100 | .016 | bone lath. Failed by break- |
| 200 | .022 | square in two. |

No. 23.

| Load | Def. | Remarks |
|---|---|---|
| 000 | .000 | Reinforcement 4 - 1/4" |
| 100 | .003 | corrugated bars |
| 200 | .007 | Mixture 1 - 2 - 4 |
| 300 | .012 | |
| 400 | .020 | Failed in shear and |
| 500 | .026 | splitting along axis of |
| 600 | .036 | bars |
| 700 | .048 | |
| 800 | .065 | |
| 900 | .072 | |
| 1000 | .083 | |
| 1100 | .096 | |
| 1200 | .110 | |
| 1300 | .125 | |
| 1400 | .141 | |
| 1500 | .157 | |
| 1600 | .173 | |
| 1700 | .193 | |
| 1750 | .216 | |
| 1800 | .228 | |
| 1850 | .235 | |
| 1900 | .271 | |
| 1950 | .324 | |

Beam No. 24.

| Load | Def. | Remarks |
|---|---|---|
| 000# | .000" | |
| 100 | .011 | Reinforcement 1 - 1/2" |
| 200 | .015 | corrugated bar |
| 300 | .024 | Failed by shearing and |
| 400 | .033 | splitting along the axis |
| 500 | .039 | of the rod. |
| 600 | .045 | |
| 700 | .058 | |
| 800 | .069 | |
| 900 | .081 | |
| 1000 | .092 | |
| 1100 | .108 | |
| 1200 | .124 | |
| 1300 | .145 | |
| 1400 | .164 | |
| 1500 | .185 | |
| 1600 | .214 | |
| 1700 | .253 | |

No. 25.

| Load | Def. | Remarks |
|---|---|---|
| 000# | .000" | Reinforcement 1 - 1/2" corrugated bar |
| 100 | .060 | |
| 200 | .016 | Failed by shearing and splitting along and parallel to steel |
| 300 | .023 | |
| 400 | .029 | |
| 500 | .039 | |
| 600 | .052 | |
| 700 | .064 | |
| 800 | .074 | |
| 900 | .092 | |
| 1000 | .106 | |
| 1100 | .124 | |
| 1200 | .142 | |
| 1300 | .172 | |
| 1400 | .188 | |
| 1500 | .204 | |
| 1600 | .289 | |

BEAM NO. 1.

8" x 12" x 2' 3/4" Kahn Bar.

| Load | Deflection |
|---|---|
| 1000 | .109 |
| 2000 | .171 |
| 3000 | .234 |
| 4000 | .328 |
| 5000 | .406 |
| 6000 | .5 |
| 7000 | .625 |
| 8000 | .718 |

Failed by compression of concrete.

Wt. of beam per linear ft. = 95.1#

BEAM NO. 7.

8" x 12" x 12' - 0" 3/4" Corr. Bar

| Load | Deflection |
|---|---|
| 1000 | |
| 2000 | .0156 |
| 3000 | .125 |
| 4000 | .234 |
| 5000 | .296 |
| 6000 | .375 |
| 7000 | |
| 8000 | |

BEAM NO. 14.

8" x 12" x 12' - 0"

| Load | Deflection |
|---|---|
| 1000 | |
| 2000 | .0156 |
| 3000 | .07 |
| 4000 | .125 |
| 5000 | .203 |
| 6000 | .281 |
| 7000 | .359 |

Beam Data

| # Beam | Age | Max. Load | Total Deflection | Concrete Allowable Load | Modulus of Rupture | Bending Moment |
|---|---|---|---|---|---|---|
| 1 | 52 | 9000# | .703" | 5000# | 13500 | 324000 |
| 2 | 49 | 400# | .097 | | 300 | 7200 |
| 3 | 52 | 1400 | .227 | 1237.2 | 1050 | 25200 |
| 4 | 52 | 1025 | .146 | 1000 | 768.75 | 18450 |
| 5 | 52 | 1100 | .26 | 781.6 | 825 | 19800 |
| 6 | 49 | 935 | .342 | 753.6 | 701.25 | 16830 |
| 7 | 40 | 7000 | .359 | 7000 | 10500 | 252000 |
| 10 | 40 | 850 | .369 | 764.6 | 637.5 | 15300 |
| 11 | 40 | 900 | .182 | 800 | 675. | 16200 |
| 12 | 40 | 250 | .184 | | 187.5 | 4500 |
| 13 | 44 | 690 | .43 | 371.9 | 617.5 | 12420 |
| 14 | 47 | 8000 | .359 | 7000 | 12000 | 28800 |
| 15 | 47 | 1325 | .343 | 1188.8 | 993.75 | 23850 |
| 16 | 43 | 1525 | .222 | 1435 | 1143.75 | 27450 |
| 17 | 43 | 1550 | .232 | 1416.3 | 1162.5 | 27900 |
| 18 | 43 | 1400 | .289 | 1389.3 | 1050 | 25200 |
| 1-2-4 (19 | 37 | 1800 | .288 | 1350 | 1350 | 32400 |
| (20 | 37 | 1800 | .271 | 1576.2 | 1350 | 32400 |
| (21 | 37 | 1400 | .249 | 1326.9 | 1050 | 25200 |
| (22 | 37 | 1850 | .337 | 1395.5 | 1387.5 | 33300 |
| (23 | 37 | 1960 | .324 | 1715 | 1470. | 35280 |
| 24 | 36 | 1750 | .253 | 1548.2 | 1312.5 | 31500 |
| 25 | 36 | 1725 | .289 | 1457.2 | 1293.75 | 31050 |
| 26 | 36 | 225 | .070 | | 168.75 | 4050 |
| 27 | 36 | 250 | .22 | 166.6 | 137.5 | 4500 |

Beam Data

| Beam | Kind of rods | Size of rods | No. of rods | Area of rods | % of steel | Steel Elastic limit | Ultimate strength | Elongation % | Crushing strength |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Kahn | 3/4" | 2 | .56 | 1.4 | 215000 | 34084 | 9.37% | 276.25 |
| 2 | Herr-ingbone lath | | | | | | | | 276.25 |
| 3 | Plain round | 1/2" | 1 | .196 | .82 | | | | 505.4 |
| 4 | Plain round | 1/2" | 1 | .196 | .82 | | | | 505.4 |
| 5 | Plain square | 1/2" | 1 | .25 | 1.04 | 9680 | 13280 | 14.9 | 505.4 |
| 6 | Plain square | 1/2" | 1 | .25 | 1.04 | | | | 505.4 |
| 7 | Corr. | 7/8" | 1 | .77 | .803 | | | | 488.41 |
| 10 | Kahn | 1/2" | 1 | .25 | 1.04 | | | | 488.41 |
| 11 | Corr. | 1/2" | 1 | .25 | 1.04 | 14000 | 23400 | 10.5 | 488.41 |
| 12 | Chain | 3/8" | 2 | .44 | 1.83 | | | | 488.41 |
| 13 | Chain | 3/8" | 2 | .44 | 1.83 | | | | 488.41 |
| 14 | Corr. | 2 1/2", 1/3" | 3 | .61 | .64 | | | | 250.31 |
| 15 | Kahn | 1/2" | 1 | .25 | 1.04 | | | | 469.4 |
| 16 | Kahn | 1/2" | 1 | .25 | 1.04 | | | | 695.6 |
| 17 | Corr. | 1/2" | 1 | .25 | 1.04 | 13070 | 21565 | 10.9 | 695.6 |
| 18 | Corr. | 1/3" | 2 | .22 | .92 | 6000 | 7830 | 23.8 | 695.6 |
| 19 | Plain round | 5/16" | 2 | .154 | .64 | | | | 618.75 |
| 20 | Kahn | 1/2" | 1 | .25 | 1.04 | | | | 618.75 |
| 21 | Round | 5/8" | 1 | .307 | 1.28 | 13500 | 18440 | 28 | 618.75 |
| 22 | Corr. | 1/2" | 1 | .25 | 1.04 | 13300 | 22100 | 13.3 | 618.75 |
| 23 | Corr. | 1/4" | 4 | .24 | 1.00 | | | | 618.75 |
| 24 | Corr. | 1/2" | 1 | .25 | 1.04 | | | | 618.75 |
| 25 | Corr. | 1/2" | 1 | .25 | 1.04 | | | | 434.6 |
| 26 | Plain | | | | | | | | 434.6 |
| 27 | Herr-ingbone | | | | | | | | |

Failure of Beams - Kahn Bar.

The beams reinforced with the Kahn bars all showed the same results in failure, so that they may be taken as a type by themselves. In no case was the failure by shear, but the concrete failed at the top in compression. The failure by splitting along the axis of the rods, so common in the other methods of reinforcments, was not seen and there was no slipping of the rod in the concrete showing that the mechanical bond was perfect. The fact that the concrete crushed in all cases shows that there was enough steel in the beam to take all the tension. Altogether this type of reinforcement is the most satisfactory in its action of any used by us.

Corrugated Bars

The failure of the beams reinforced with these bars was uniformly in shear and by splitting along the plane of the bars. In only a few cases was there any indication of crushing of the concrete. In some cases there was evidence of slipping of the bars in the concrete. The fact that shearing was so common in this type of beam leads us to believe that the corrugated bars are inferior to the Kahn bars for preventing this mode of failure. The mechanical bond is not so good as in the Kahn bar but for large bars there is so little slip as to be unnoticed. The fact that the beams split along the plane of the bars is probably due to cross section of the concrete being smaller there than elsewhere in the beams.

## Plain Bars

These failed in much the same manner as the corrugated bars except there was much more evidence of the bars not being in perfect mechanical bond with the concrete. The beams failed very readily and the longitudinal crack along the axis of the bars was noticed at the same time as the crack extending up to the top of the beam from the rods, showing that the rods were yielding because of their low elastic limit. These bars were not so satisfactory in their action as the corrugated bars.

## Chain

The deflections of the beams reinforced with chains were excessive, caused by the slack coming out of the chain. The mechanical bond appeared to be perfect but as the concrete began to fail in tension under the chain, the split along the reinforcement was not noticed. The final failure was by crushing of the concrete along the top of the beam.

## Herringbone lath

In both cases this broke short off at small loads, showing that there was not enough reinforcment to take the entire tension load. This reinforcement takes up so much of the space along its axis that the concrete is not well joined together from the compression to the tension parts. This kind of reinforcement was not satisfactory at all and should not be be used for beam sections.

## Plain Concrete.

This was not very satisfactory owing partly to the trouble in getting a beam to stand, being taken out of the mold after it had remained in the mold longer than had the reinforced beams, and to the fact that the loads held were very small. The deflection shown was quite small showing plain concrete will answer for light loads only. For heavy loads plain concrete is not strong enough to give good service unless in very large masses and even then its action is very treacherous.

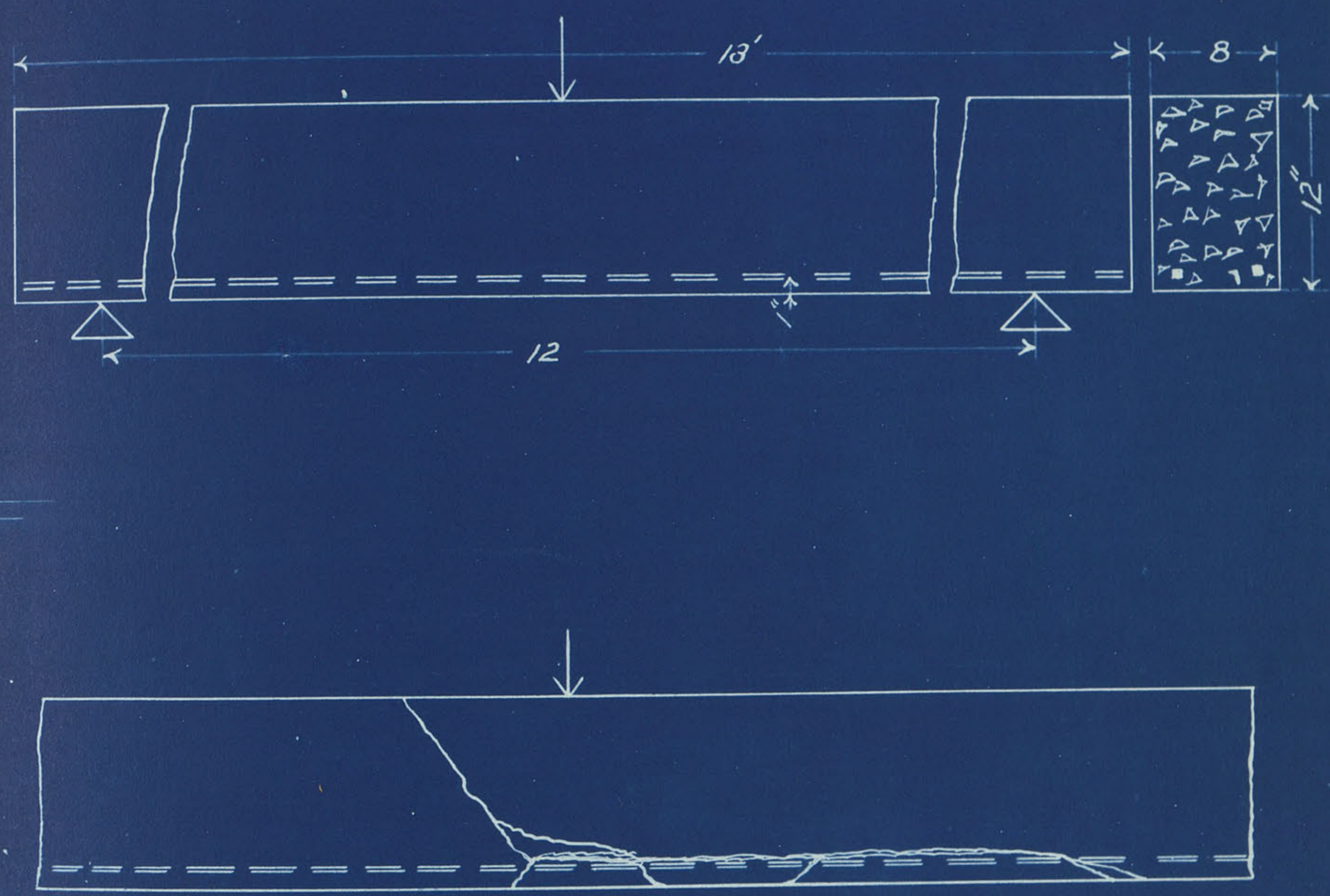
## Conclusions.

From the results obtained from these tests it is evident that the Kahn bars are the best for beam reinforcing; for, while the loads carried by the beams with Kahn bars were no larger than those with corrugated bars, the deflection for the given loads was uniformly smaller, so in places where f deflection is to be taken into account the Kahn bar should be used. They cause the concrete to fail in its strongest form, that is, by compression as they are effective in preventing shear.

Chains are not permissible at all as they allow too much deflection for their use in buildings. They also allow the concrete to be stressed in tension, its weakest point.

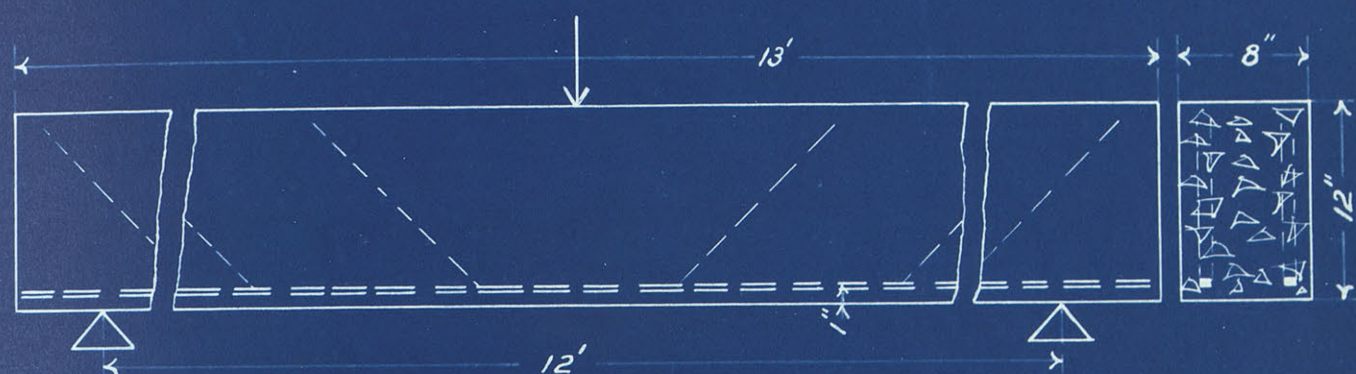
Round and square wrought iron bars with smooth surface do well for small loads but the excessive stretch of these bars renders them unsuitable for beam sections, as they allow too much deflection for a given load.

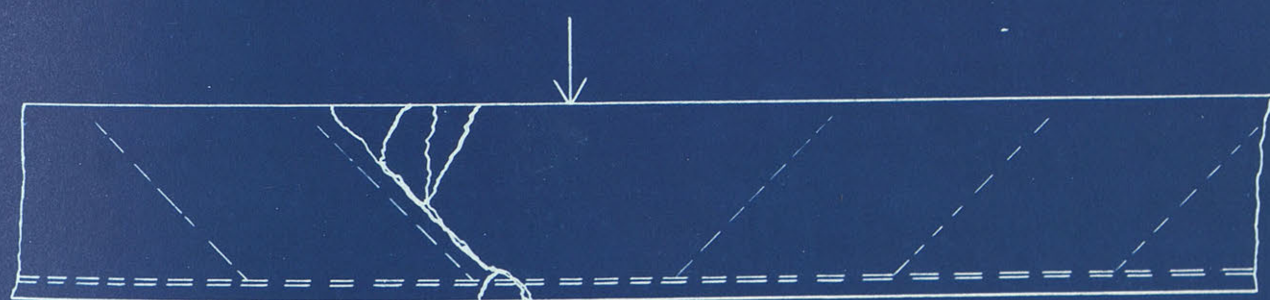
# BEAMS No 7 & 14.




TYPICAL MODE OF FAILURE
FOR CORR. BAR REINFORCEMENT
BREAKING LOADS 7000# & 8000#

BEAM No 1.

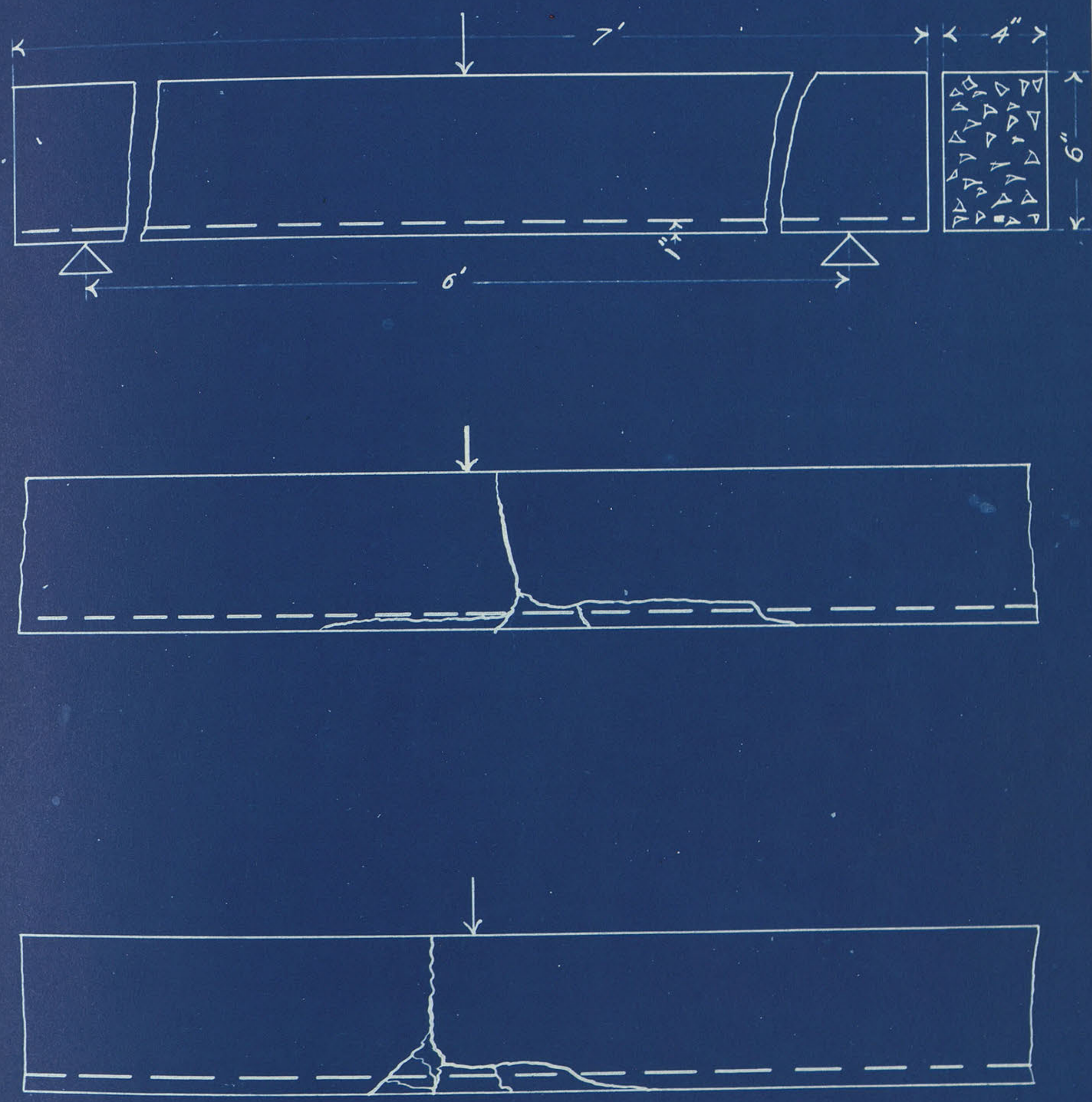


REINFOCEMENT 2-$\frac{3}{4}$" KAHN BARS

BREAKING LOAD 9000#

TYPICAL MODE OF FAILURE




TYPICAL MODES OF FAILURE
FOR ROUND AND SQUARE BARS

Herringbone lath was valueless for beams . For beam sections, then, it is best to use some form of steel reinforcement which has a high elastic limit for the given section and which has some form of provision made to prevent shear and slipping of the bars in the concrete.

As for the concrete, it stands to reason that the 1 - 2 - 4 mixture should be superior to the 1 - 2 - 5 mixture, which accounts for the high values of failure of some of the beams. In the beams of the 1 - 2 - 4 mixture which were uniformly good, we found that if several bars giving the same total area in cross section of metal as a single bar of the same material were used, the strength was considerably increased. For instance, the beam with 4, 1/4" corrugated bars was stronger than any beam with 1, 1/2" bar with the same cross section area. The same results were noticed in beams 17 and 18, of the same age and mixture. The 2, 1/3" bars were superior to the 1, 1/2" bar. Considering the low loads at which the concrete itself failed the beams were all reinforced from 3 to 4 times as much as was needed. The concrete was made very carefully and the beams were handled in the most approved fashion and the results used were only from good beams. We found that after a beam had been badly shaken or any part broken, it was of no value for testing purposes.

The tests on the neat cement showed that the cement was of an inferior quality. This explains the low breaking load and the fact that the beams were over reinforced.