CONSTRUCTION AND TESTS

of

REINFORCED CONCRETE FLOOR SLABS

and

REINFORCED CONCRETE FLOOR SYSTEM.

THESIS

FOR

The DEGREE of

BACHELOR of SCIENCE

in

CIVIL ENGINEERING.

UNIVERSITY OF MISSOURI.

1911.

Hugh Chilton
H. C. Rogers. 1889
Robert Lincoln III
R. L. Prehn. 1885
William Harrison
W. H. Maclay. 1889

TABLE OF CONTENTS.

Construction and Tests of Reinforced Concrete Floor Slabs and Reinforced Concrete Floor System.

Introduction.

In the use of reinforced concrete for the construction of buildings, it is of importance that the structure be made as light as is consistent with strength. Especially is this true of concrete floors in concrete or steel structures where the dead load of the floor is an important item; being usually a large per cent of the designed working load.

The cost of forms in the placing of concrete is one of the very important items in the construction of concrete floors. This is especially true for floors at elevated heights, such as the higher floors of office buildings, factories and warehouses. Where such floors are of "monolithic" or solid construction, the forms must be built in place and all material hoisted and poured into them. As these tight forms are often difficult to remove without injury, they can only be used a few times.

In the following design of floor system, some of these difficulties are eliminated. The beams and columns are constructed in place, much the same as in the monolithic system,

while the slabs may be built at any time or place and later hoisted into position. These slabs may be manufactured in sets of standard forms which can be used over and over again. When convenient, the slabs may be made at some locality other than the building site, and then be hauled or even shipped to the place of construction.

Object.

It is the object of this thesis to make tests of rigidity on different widths and thicknesses of slabs, using a few of the more prominent brands of cement. The further object of this thesis is to determine the rigidity of a complete floor system, made of these slabs and subjected to a uniform load.

General Description of Tests.

The test consisted of two parts:

(1). Tests on individual slabs.

(2). Tests on completed floor system.

In testing the individual slabs, two methods were used:

(a). Concentrated loads at 1/3 points, and

(b). Uniform load.

In testing the completed floor system, a uniform load only was used.

In making and testing of slabs, methods of mixing and placing of concrete as well as of loading the finished slab were made to conform as nearly as possible with conditions usually met with in practical work. It was impossible to load slabs wider than 12 inches with concentrated load as they could not be put in a testing machine. Larger sizes were therefore tested under uniform load. In both cases, however, the slab was supported exactly as they would be in actual practice. The usual specification for strength is that the floor should support a certain load per square foot, distributed uniformly over the whole floor.

The deflection of slabs and beams under various loads were recorded until a certain load was reached. The individual slabs were tested up to a load of 400 pounds per square foot, while the floor was tested up to a load of 180 pounds per sq. foot. No attempt was made to test slabs to destruction. We did not design the slabs for any certain load, but constructed them of given dimensions and tested for strength and rigidity.

Materials.

Cement:---Four standard brands of Portland cement were used; Atlas, Iola, Sunflower and Cowboy. These were purchased on the market and represented average quality of these brands. Tests on these cements were made in Laboratory using the standard methods recommended by the Committee of The American Society for Testing Materials.

Brand	Sp. Gr.	Tension #/ sq. in.			Compression #/ sq. in.		
		24 hr.	7 da.	28 da.	24 hr.	7 da.	28 da.
Atlas	3.150	396	680	700	2852	5476	8354
Sunflower	3.106	175	590	680	1880	10120	12423
Iola	3.240	145	430	650	1280	4990	7102
Cowboy	3.291	223	596	761	1365	5099	7228

Sand:---Sand used was Hinkson Creek sand, and was unscreened. Specific gravity was 2.62 and percentage of voids about 33 per cent.

Stone:---The stone for the aggregate was a crushed local limestone, known as Boone County Limestone, and ranged in size from 1 1/4" to 1/4" being free from dust. This stone is of medium quality and is in general use for concrete work in this locality, giving satisfactory results. Tests show a specific gravity of 2.62 and a percentage of voids of 46.00%.

Steel:---Reinforcing used was 3/8" diam. medium steel rods for slabs and 7/8" diam. medium steel rods for floor beams.

Method of Mixing Concrete.

The ingredients were proportioned by volume; one part of cement (packed), two parts of sand, four parts of crushed stone. The sand and cement were mixed dry until mixture was uniform in color, showing no streaks of sand or cement. Water was then added to this and the mass thoroughly mixed with shovels. The moistened stone was then added and the whole turned several times so that every stone was thoroughly covered with mortar. In this way, a stronger concrete is formed than where all ingredients are mixed in one operation. Enough water was used to make a rather wet mixture in order that all parts of the reinforcement be reached by the concrete.

Forms.

The forms for the slabs were made of yellow pine timber, the bottom being 1" in thickness, and the sides of 4" x 4". The sides of the forms were bolted to the bottom by 1/2" bolts provided with nuts and washers. The sides of the forms were beveled so that the slabs could be removed without difficulty.

The channel sections of the slabs were obtained by using wood centers. These centers were of such dimensions as to leave about a 4 in. width on each side and about 9 in. on the ends. The depth was 2 in.

The purpose of these centers was to reduce the weight of the slab, and also the quantity of concrete.

The forms for the beams and piers were made of 1 1/4" timber thoroughly braced and clamped to prevent settling and bulging. Special care was taken in the construction of the forms to provide for their removal without injury. The forms on the floor system were removed after thirty days, and the slabs were taken out after seven days.

After the concrete had set a little, the centers were removed. As all the forms and centers were well oiled before using, no difficulty was experienced in their removal.

Reinforcement.

The rods used for reinforcing the slabs were bent thru an angle of 180° on each end. Two rods were wired together as shown in Plate 6. One set of rods was suspended about 2" from the inside edges of the forms by small wires.

The steel reinforcing for the beams of the floor system is shown in Plate 9. These rods were securely wired so that when the concrete was poured, they would not be jarred out of position.

Apparatus for Testing.

As there was no machine in the laboratory capable of handling slabs of widths greater than 12", or of applying uniform loads, special apparatus was constructed for making the tests.

The 12" slabs were tested in the laboratory, using the Olsen 50,000# capacity transverse testing machine. The slabs were supported on rollers 54" apart, and loaded at one-third points. Plates at bearing places were set in plaster paris to provide for even distribution of load. Deflections were taken with a Riehle deflectometer for every 100# load increment.

The 15", 18" and 21" slabs were tested with a uniform load of sand. The test table was constructed with knife edges 58" apart. The slab was placed on these knife edges, and an even bearing secured. A crib was then placed upon the slab and a uniform loading of sand was applied, by filling it with sand.

The crib consisted of a strong box 4 ft. high, 5 ft. long and of same width as the slab being tested. Deflections were then taken with the Riehle deflectometer for each 50 lbs. increment of load.

The crib for the floor system was built around the entire floor, and then divided into three sections, one around each panel.

The load used was a uniform load of sand for the end panel, and of rock for the center panel, and was applied

at increments of 60 lbs. per sq. ft.

Sticks 1/2 in. square and 2 ft. long were suspended from the center of each slab and each beam, and also at the points of junction of the longitudinal beams and cross beams. At the end of each stick was a scale graduated to 1/20 of an inch.

These scales were read with a Buff and Buff precise level to .005 of an inch, and the deflections due to each additional load secured.

Conclusions.

While the limited nature of the foregoing tests does not warrant the drawing of positive conclusions, yet the following facts seem evident.

(1). The channel section in the slab shows a marked effect on the strength and rigidity.

(2). Rigidity under load seems to be independent of the width of the slab.

(3). Owing to the lesser weight of the 12" slabs, they are much easier to handle than the larger slabs.

(4). As all sizes of slabs have the same area of steel, the wider slabs have a less percentage and are therefore slightly more economical.

(5). That the minimum depth tested, 4" gives sufficient strength to support a uniform load of at least 500 to 600 lbs. per square foot, which is sufficient strength for any ordinary construction

TABLE I

21" SLABS

BRAND	THICKNESS	AGE	WEIGHT	DEFLECTIONS UNDER LOADS LBS PER SQUARE FOOT									
				LBS.	0	50	100	150	200	250	300	350	400
COWBOY	4 in.	36da.	350lbs.		0	.010	.015	.020	.027	.036	.044	.053	.062
IOLA	4 "	172"	380 "		0	.006	.009	.012	.016	.019	.021	.024	.025
COWBOY	4½ "	36"	383 "		0	.007	.012	.018	.027	.037	.044	.051	.057
COWBOY	4½ "	36"	390 "		0	.009	.019	.025	.032	.039	.045	.049	.054
SUNFLOWER	4½ "	154"	450 "		0	.003	.005	.010	.013	.015	.016	.018	.021

TABLE 2

I8" SLABS

BRAND	THICKNESS	AGE	WEIGHT	LBS.	DEFLECTIONS UNDER LOADS LBS. PER SQUARE FOOT								
					0	50	I00	I50	200	250	300	350	400
ATLAS	4 in.	65da.	280lbs.		0	.006	.0I4	.027	.043	.062	.076	.088	.093
ATLAS	4 "	78"	265 "		0	.009	.02I	.0[illegible]7	.072	.084	.096	.III	.I24
ATLAS	4 "	72"	275 "		0	.0I8	.030	.045	.062	.080	.098	.II3	.I23
COWBOY	4½ "	43"	300 "		0	.007	.0I7	.029	.032	.057	.082	.II6	.I22
COWBOY	4½ "	43"	360 "		0	.004	.008	.0II	.0I3	.0I6	.0I9	.022	.026
COWBOY	4½ "	43"	360 "		0	.007	.0I3	.0I6	.02I	.022	.050	.065	.074
ATLAS	4½ "	63"	337 "		0	.009	.0I3	.0I8	.024	.030	.038	.053	.083
ATLAS	4½ "	65"	340 "		0	.006	.0I[illegible]	.0I2	.0I8	.02I	.025	.030	.044
SUNFLOWER	4½ "	I49"	333 "		0	.004	.008	.0I2	.0I6	.020	.023	.026	.030
IOLA	4½ "	I63"	340 "		0	.006	.0I2	.0I6	.020	.023	.029	.033	.042
ATLAS	4½ "	72"	3I0 "		0	.0I5	.028	.035	.050	.06I	.069	.080	.085
ATLAS	4½ "	72"	320 "		0	.0I9	.026	.039	.050	.057	.064	.076	.083

TABLE 3

15" SLABS

BRAND	THICKNESS	AGE	WEIGHT	DEFLECTIONS UNDER LOADS LBS. PER SQUARE FOOT									
				LBS.	0	50	100	150	200	250	300	350	400
SUNFLOWER	4in.	151da.	250lbs.		0	.005	.010	.014	.018	.021	.024	.027	.029
ATLAS	4"	75"	245 "		0	.006	.015	.025	.032	.040	.046	.052	.058
ATLAS	4"	65"	240 "		0	.014	.023	.030	.037	.043	.051	.058	.065
COWBOY	4"	68"	245 "		0	.008	.014	.023	.030	.044	.055	.068	.079
IOLA	4½"	165"	280 "		0	.004	.007	.009	.012	.015	.017	.019	.021
ATLAS	4½"	80"	275 "		0	.004	.008	.012	.015	.019	.022	.029	.032
ATLAS	4½"	80"	275 "		0	.006	.012	.017	.025	.031	.036	.051	.062
ATLAS	4½"	68"	284 "		0	.004	.008	.012	.015	.019	.024	.027	.029
COWBOY	4½"	48"	292 "		0	.003	.006	.009	.013	.016	.020	.024	.028

TABLE 4

12" SLABS

LBS.	BRAND	THICKNESS	AGE	WEIGHT
	COWBOY	4 in.	44 da.	205 lbs.
	SUNFLOWER	4 "	154 "	205 "
	ATLAS	4 "	24 "	198 "
	ATLAS	4 "	105 "	192 "
	COWBOY	4½ "	51 "	235 "
	IOLA	4½ "	168 "	224 "
	COWBOY	4½ "	56 "	225 "
	ATLAS	4 " Channel up	105 "	198 "
	DEFLECTIONS UNDER LOADS(CONCENTRATED)			
300	.006	.005	.000	.004	.007	.003	.003	.009
400	.012	.007	.006	.007	.009	.004	.004	.012
500	.018	.009	.015	.010	.011	.005	.005	.016
600	.024	.012	.022	.012	.013	.007	.007	.024
700	.030	.016	.030	.017	.016	.009	.010	.030
800	.037	.022	.038	.020	.018	.011	.014	.035
900	.043	.028	.046	.025	.021	.013	.021	.042
1000	.052	.036	.050	.035	.024	.016	.032	.050
1100	.060	.046	.062	.043	.037	.018	.046	.058
1200	.070	.057	.070	.050	.052	.021	.068	.065
1300	.080	.065	.081	.058	.066	.024	.081	.078
1400	.088	.076	.090	.070	.076	.028	.098	.085
1500	.095	.088	.103	.080	.086	.040	.114	.096
1600	.106	.101	.118	.092	.094	.046	.133	.107
1700	.117	.114	.130	.100	.104	.056	.144	.118
1800	.127	.127	.149	.110	.112	.068	.159	.135
1900	.138	.137	.167	.120	.126	.078	.174	.145

TABLE 4

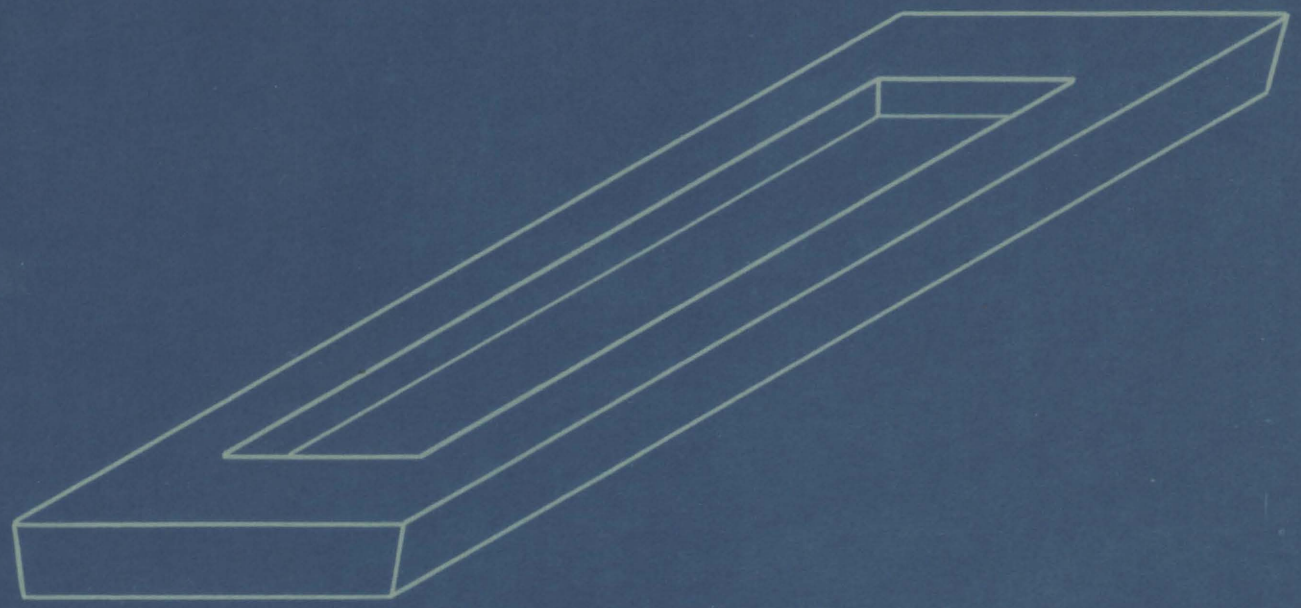
12" SLABS

LBS.	BRAND	THICKNESS	AGE	WEIGHT
	COWBOY	4 in.	44 da.	205 lbs.
	SUNFLOWER	4 "	154 "	205 "
	ATLAS	4 "	24 "	198 "
	ATLAS	4 "	105 "	192 "
	COWBOY	$4\frac{1}{2}$ "	51 "	235 "
	IOLA	$4\frac{1}{2}$ "	168 "	224 "
	COWBOY	$4\frac{1}{2}$ "	56 "	225 "
	ATLAS	4 "	105 " Channel up	198 "
	DEFLECTIONS UNDER LOADS (CONCENTRATED)			
2000	.148	.148	.197	.129	.133	.087	.208	.174
2100	.161	.160	.210	.141	.146	.098	.224	.194
2200	.175	.172	.225	.155	.155	.109	.243	.
2300	.189	.185	.245	.165	.165	.118	.253	
2400		.195	.270	.182	.175	.128	.263	
2500		.208	.305	.197	.185	.138	.282	
2600		.219	.344	.210	.195	.146	.320	
2700		.230	.387	.225	.202	.154	.350	
2800		.242	.452	.235	.211	.164	.384	
2900		.253	.	.250	.223	.172	.430	
3000		.265	.	.263	.234	.181	.478	
3100		.278		.275	.245	.193	.	
3200		.288		.290	.263	.198		
3300		.300		.303	.278	.208		
3400		.316		.328	.326	.215		
3500		.330		.360		.225		
3600		.349				.234		
3700		.375				.244		
3800						.260		

TABLE 5

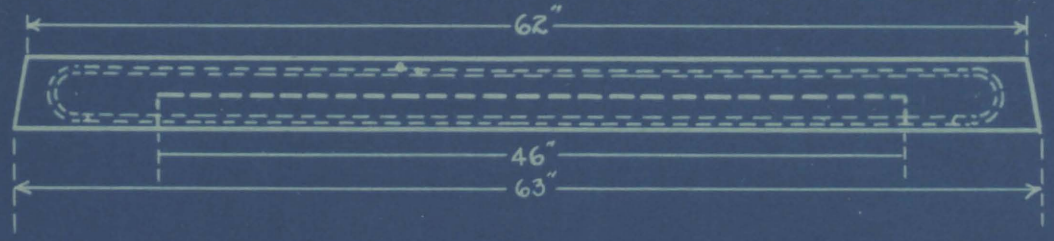
FLOOR SYSTEM

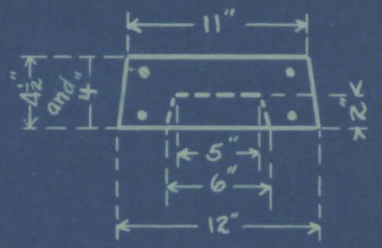
POINT		DEFLECTIONS. UNIFORM LOAD				
	LBS.	0	60	120	180	
1		0	.015	.015	.060	
2		0	.050	.050	.090	
3		0	.040	.050	.100	
4		0	.045	.080	.180	
5		0	.035	.055	.105	
6		0	.050	.060	.105	
7		0	.015	.020	.080	
8		0	.000	.005	.035	
9		0	.025	.050	.050	
10		0	.045	.080	.135	
11		0	.045	.065	.115	
12		0	.050	.090	.150	
13		0	.050	.095	.150	
14		0	.070	.110	.180	
15		0	.055	.090	.180	
16		0	.040	.085	.170	
17		0	.050	.065	.120	
18		0	.040	.050	.150	
19		0	.045	.045	.065	
20		0	.015	.030	.055	
21		0	.025	.060	.110	
22		0	.035	.050	.100	
23		0	.050	.065	.105	
24		0	.050	.065	.120	
25		0	.055	.065	.190	
26		0	.025	.065	.120	
27		0	.030	.065	.120	
28		0	.040	.050	.100	
29		0	.010	.010	.040	
30		0	.045	.050	.080	
31		0	.010	.010	.050	
32		0	.055	.085	.155	
33		0	.060	.100	.150	
34		0	.035	.040	.070	
35		0	.020	.040	.095	
36		0	.035	.045	.100	
37		0	.030	.035	.075	
38		0	.030	.050	.065	



TYPE of SLAB

PLATE 1



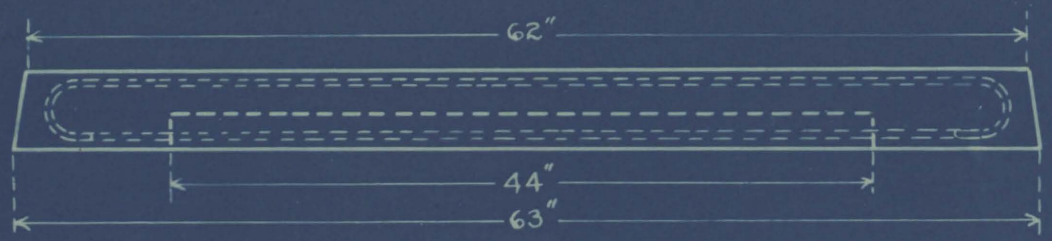


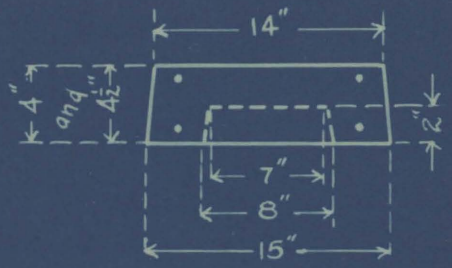
DIMENSIONS OF

12" FLOOR SLABS

Scale 1" = 1'-0"

PLATE 2



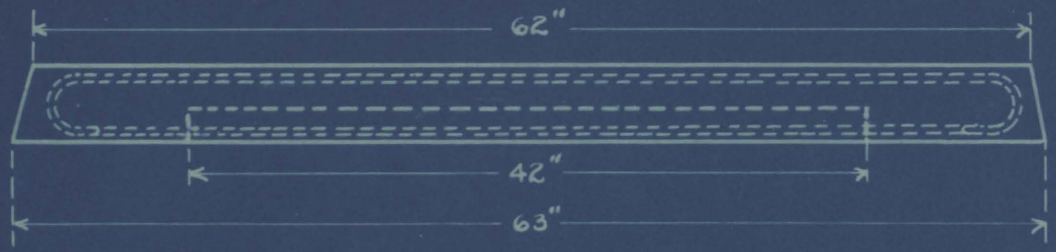


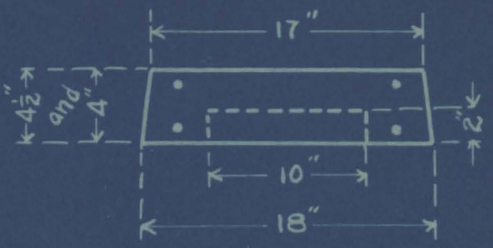
DIMENSIONS OF

15" FLOOR SLABS

Scale 1"=1'-0"

PLATE 3



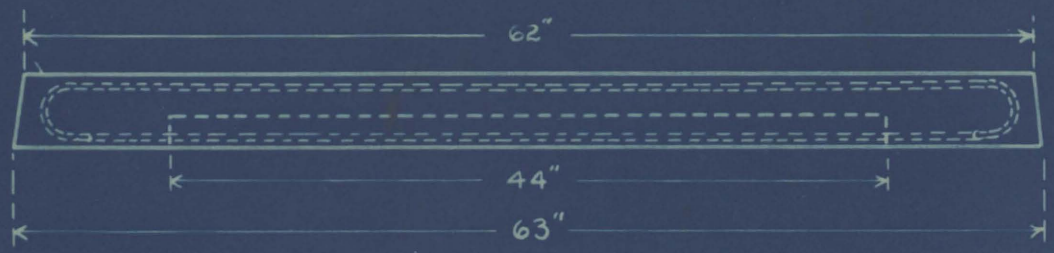


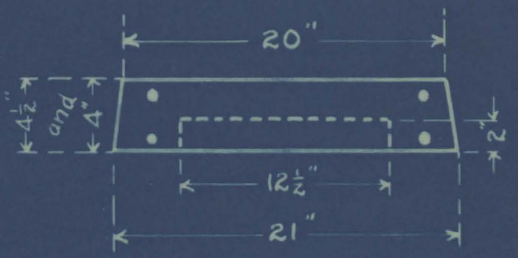
DIMENSIONS OF

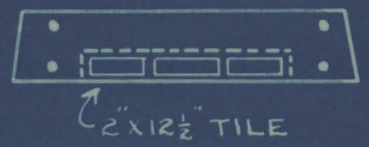
18" FLOOR SLABS

Scale 1"=1'-0"

PLATE 4





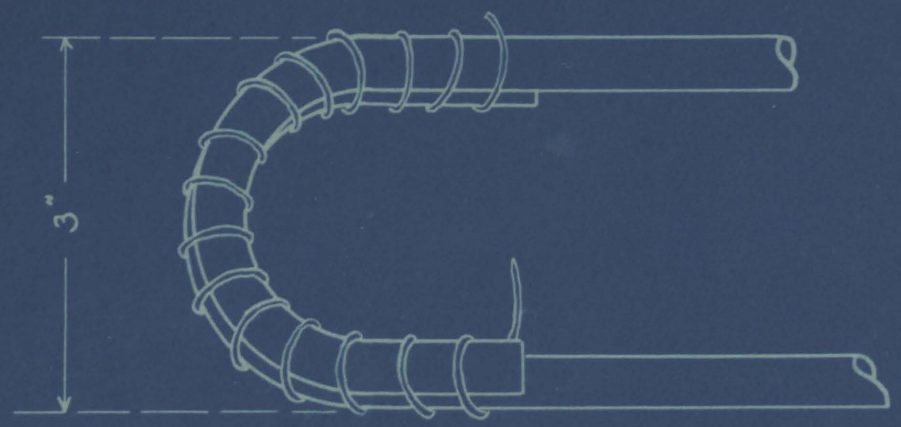


DIMENSIONS OF

21" FLOOR SLABS

Scale 1"=1'-0"

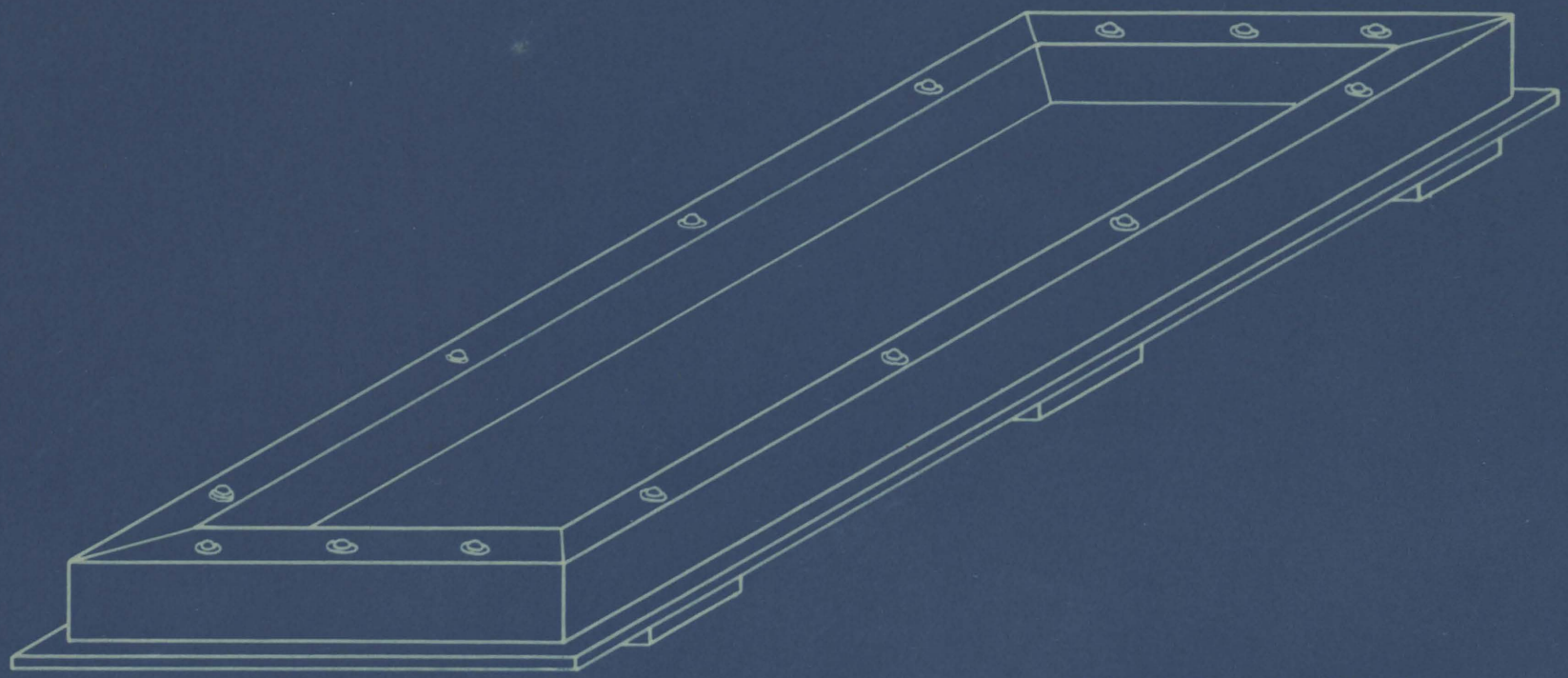
PLATE 5



TYPE OF REINFORCING FOR SLABS

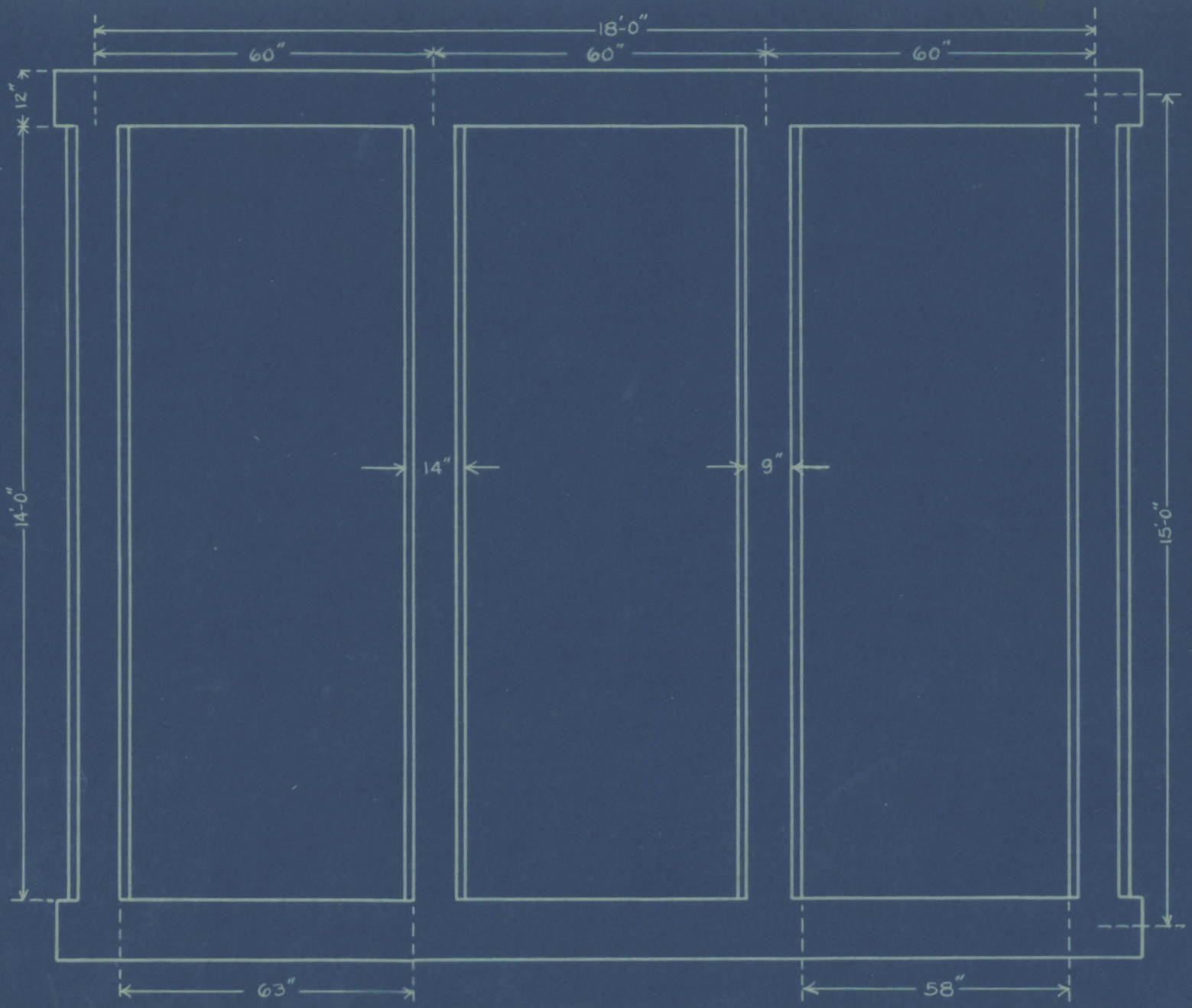
3/8" Medium Steel Rods, bent and wired together at ends as shown.

PLATE 6



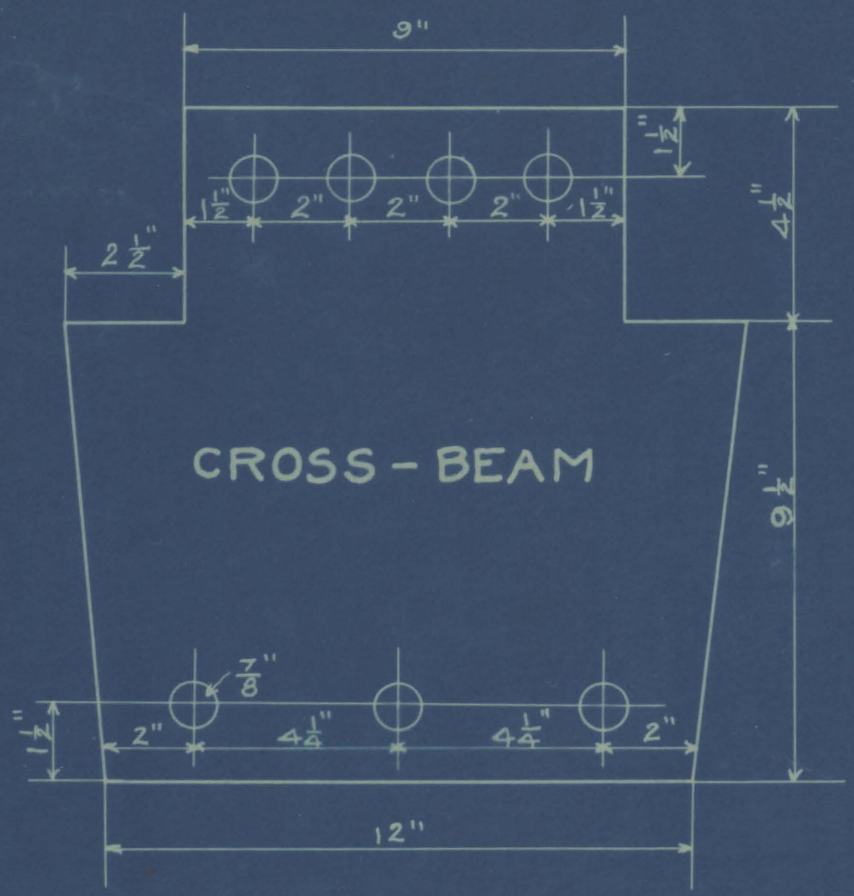
TYPE of FORM

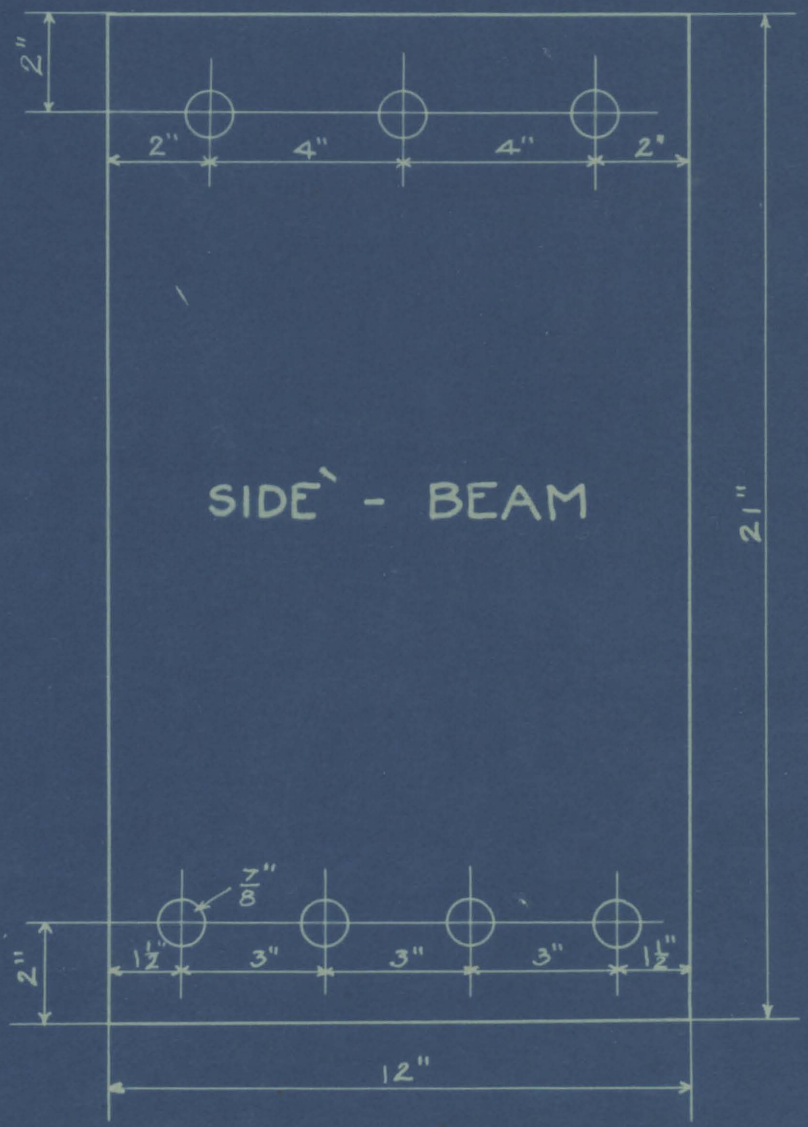
PLATE 7



PLAN of FLOOR BEAMS
Scale 3/8" = 1'

PLATE 8





SECTIONS OF BEAMS

SCALE 1" = 4 in.

PLATE 9

35 36

Sunflower	8	4"x21"
Age: 165 da.		Wt 382#
Sunflower	7	4"x21"
Age: 165 da.		Wt 375#
Iola	6	4½"x21"
Age: 184 da.		Wt 425#
Iola	5	4½"x21"
Age: 184 da.		Wt 425#
Iola	4	4"x21"
Age: 184 da.		Wt 384#
Atlas	3	4"x21"
Age: 138 da.		Wt 400#
Atlas	2	4½"x21"
Age: 138 da.		Wt 435#
Atlas	1	4"x21"
Age: 138 da.		Wt. 380#

31 32

Sunflower	18	4"x18"
Age: 158 da.		Wt 283#
Sunflower	17	4"x18"
Age: 158 da.		Wt 285#
Iola	16	4"x18"
Age: 184 da.		Wt. 295#
Iola	15	4"x18"
Age: 184 da.		Wt. 287#
Iola	14	4½"x18"
Age: 184 da.		Wt. 330#
Sunflower	13	4½"x18"
Age: 158 da.		Wt. 317#
Iola	12	4½"x15"
Age: 158 da.		Wt. 277#
Sunflower	11	4½"x15"
Age: 220 da.		Wt. 282#
Sunflower	10	4½"x15"
Age: 220 da.		Wt 272#
Iola	9	4"x12"
Age: 158 da.		Wt. 198#

33

Cowboy	30	4"x12"
Age: 75 da.		Wt 205#
Cowboy	29	4½"x15"
Age: 75 da.		Wt 280#
Cowboy	28	4"x15"
Age 75 da.		Wt. 260#
Cowboy	27	4"x18"
Age: 55 da.		Wt 315#
Iola	26	4"x15"
Age: 172 da.		Wt. 245#
Iola	25	4"x15"
Age: 158 da.		Wt 245#
Iola	24	4"x15"
Age: 172 da.		Wt 247#
Sunflower	23	4½"x12"
Age: 158 da.		Wt. 224#
Sunflower	22	4"x12"
Age: 158 da.		Wt. 192#
Iola	21	4"x12"
Age: 172 da.		Wt. 194#
Iola	20	4½"x12"
Age: 172 da.		Wt 222#
Sunflower	19	4½"x12"
Age: 158 da.		Wt 217#

34

37 38

PLATE 10

PLATE 11

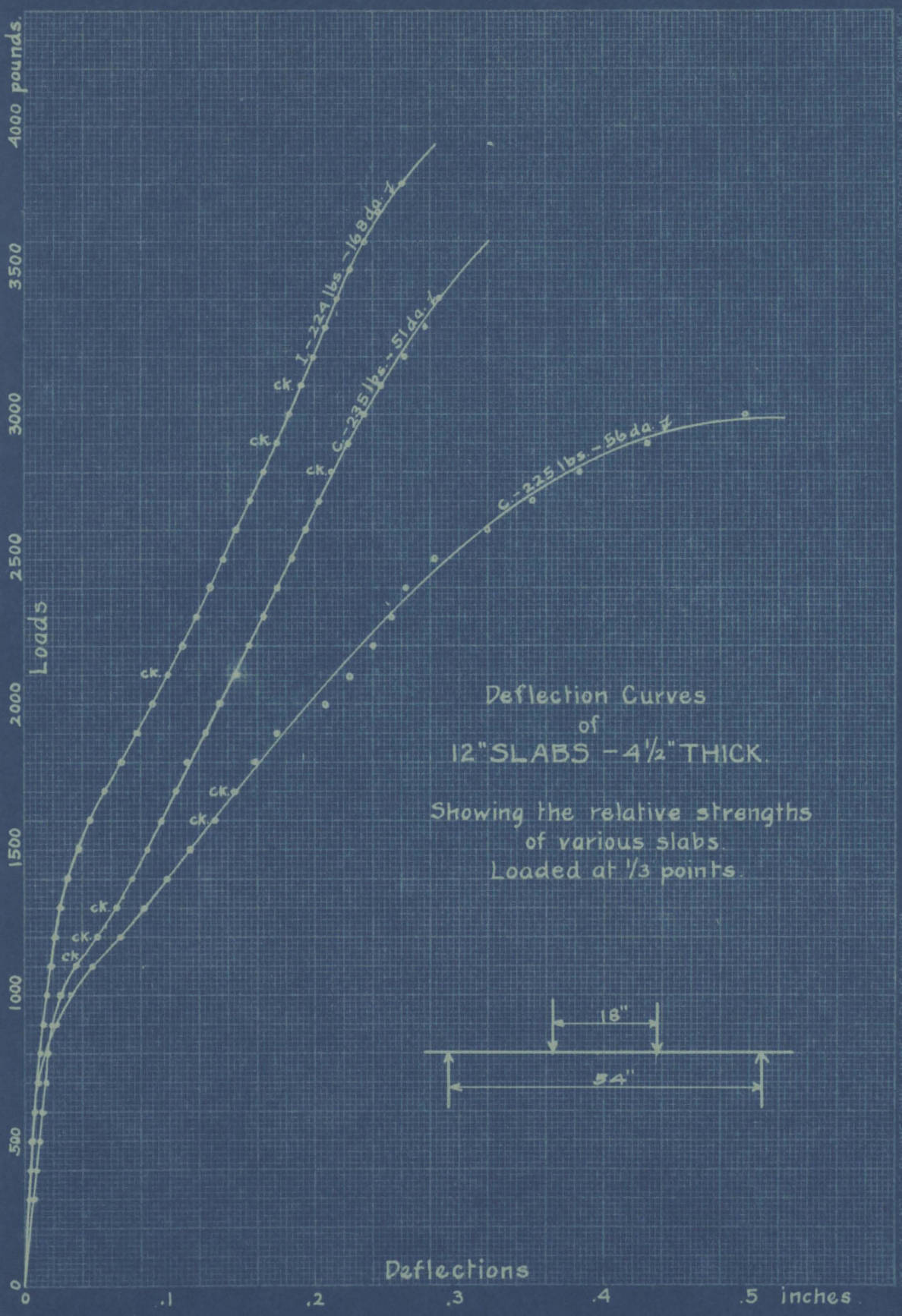

Loads
4000 pounds.
3500
3000
2500
2000
1500
1000
500
0
Deflections
0
.1
.2
.3
.4
.5 inches
I-224 lbs.-168 da.
C-235 lbs.-51 da.
C-225 lbs.-56 da.
ck.
Deflection Curves
of
12" SLABS - 4½" THICK.
Showing the relative strengths
of various slabs.
Loaded at ⅓ points.
18"
54"

PLATE 12

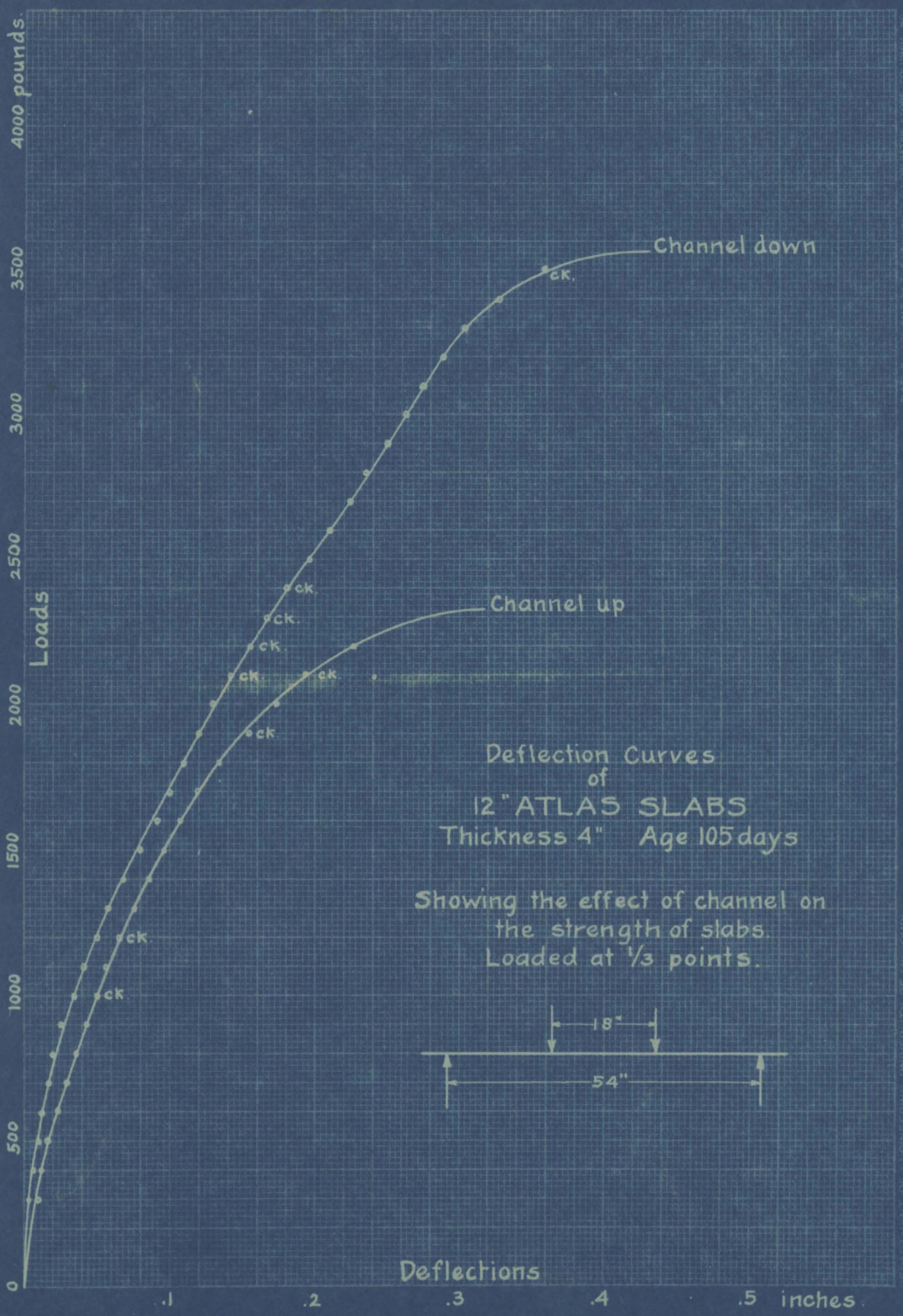

Loads
4000 pounds
3500
3000
2500
2000
1500
1000
500
0
Channel down
Channel up
ck.
Deflection Curves
of
12" ATLAS SLABS
Thickness 4" Age 105 days
Showing the effect of channel on
the strength of slabs.
Loaded at 1/3 points.
18"
54"
Deflections
.1
.2
.3
.4
.5 inches

PLATE 13

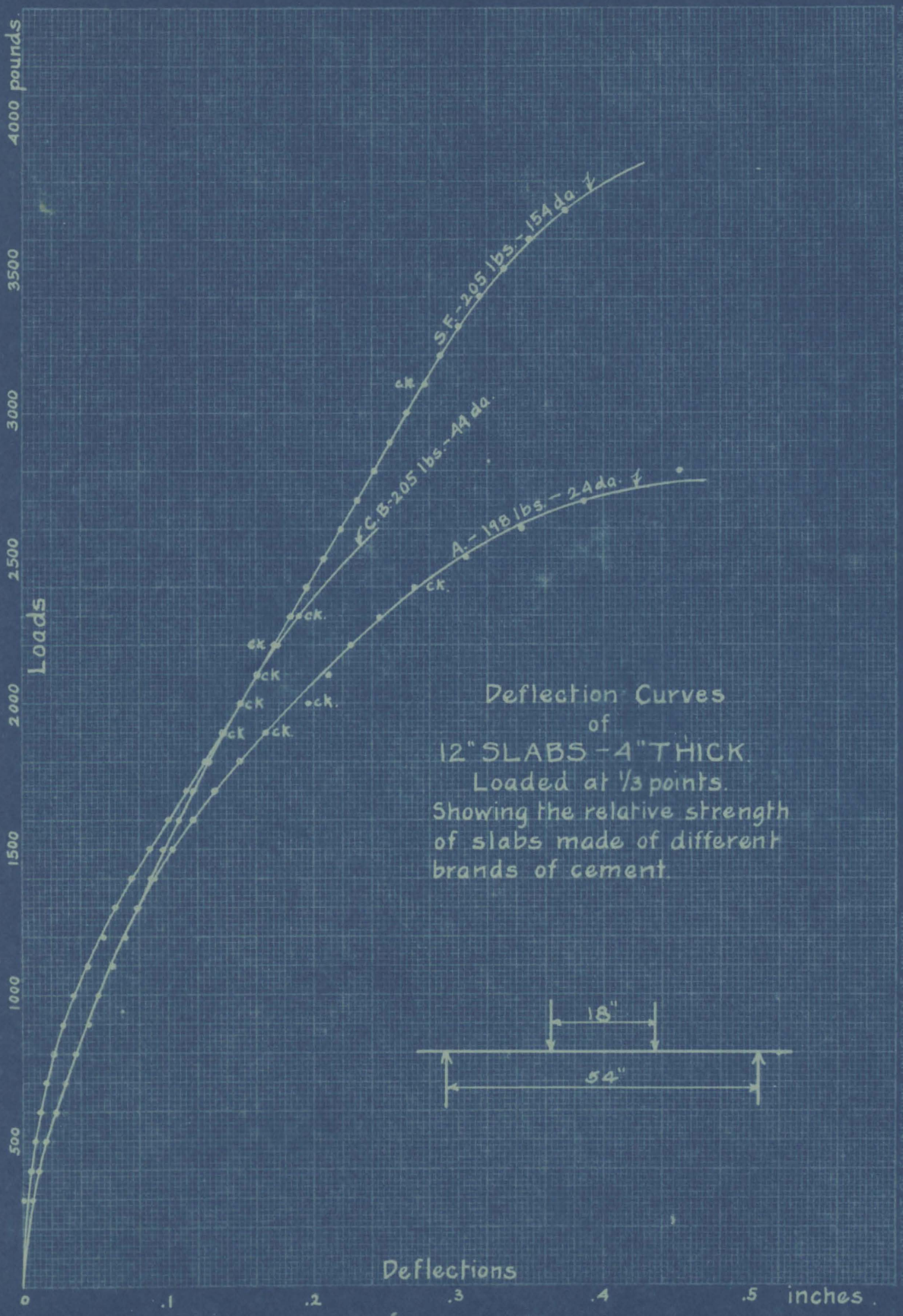
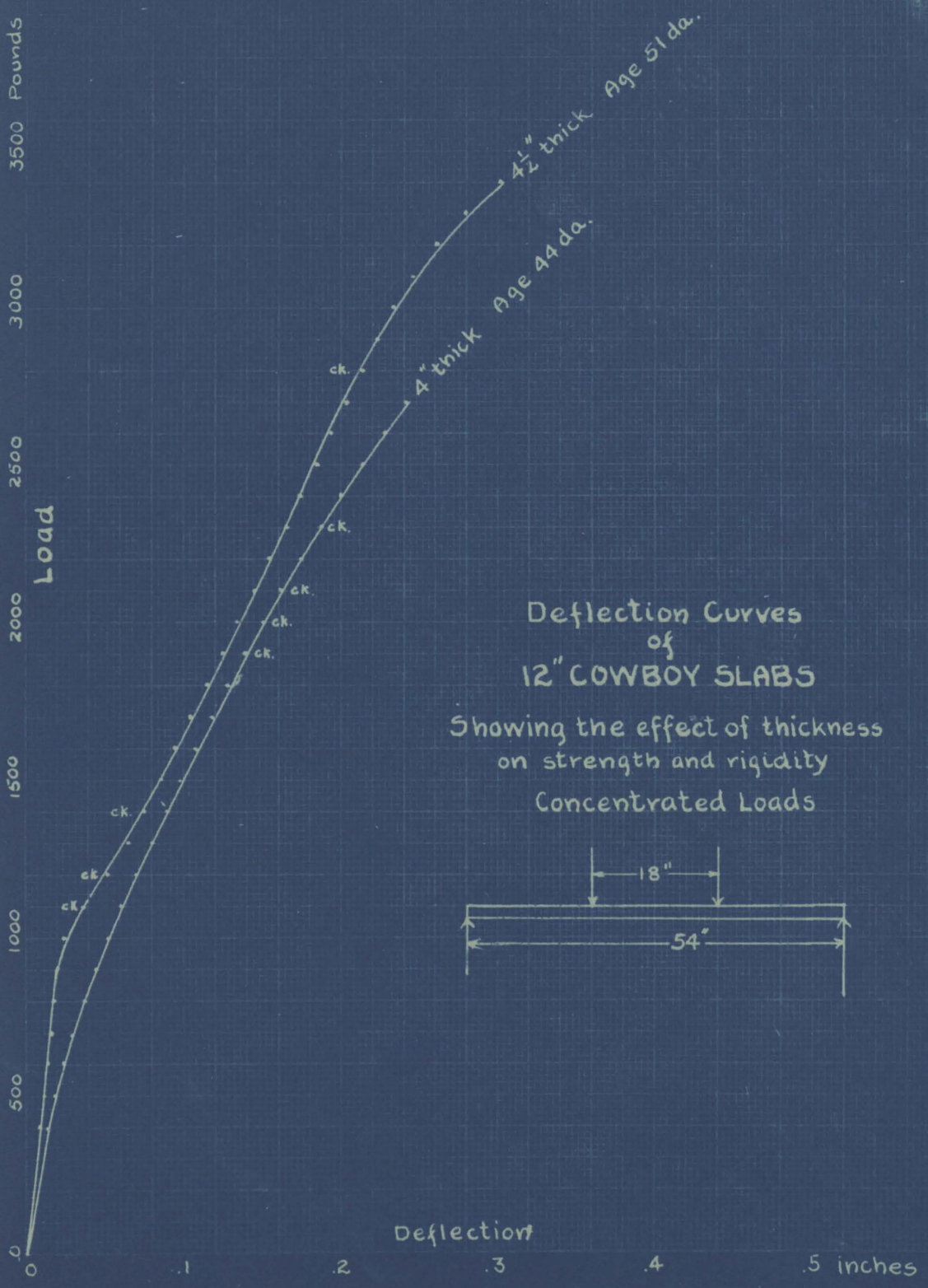

Loads
4000 pounds
3500
3000
2500
2000
1500
1000
500
0
.1
.2
.3
.4
.5
inches.
Deflections
S.F.-205 lbs.-154 da.
C.B.-205 lbs.-44 da.
A.-198 lbs.-24 da.
ck.
Deflection Curves
of
12" SLABS - 4" THICK.
Loaded at 1/3 points.
Showing the relative strength
of slabs made of different
brands of cement.
18"
54"

PLATE 14



Deflection Curves
of
12" COWBOY SLABS

Showing the effect of thickness
on strength and rigidity

Concentrated Loads

PLATE 15

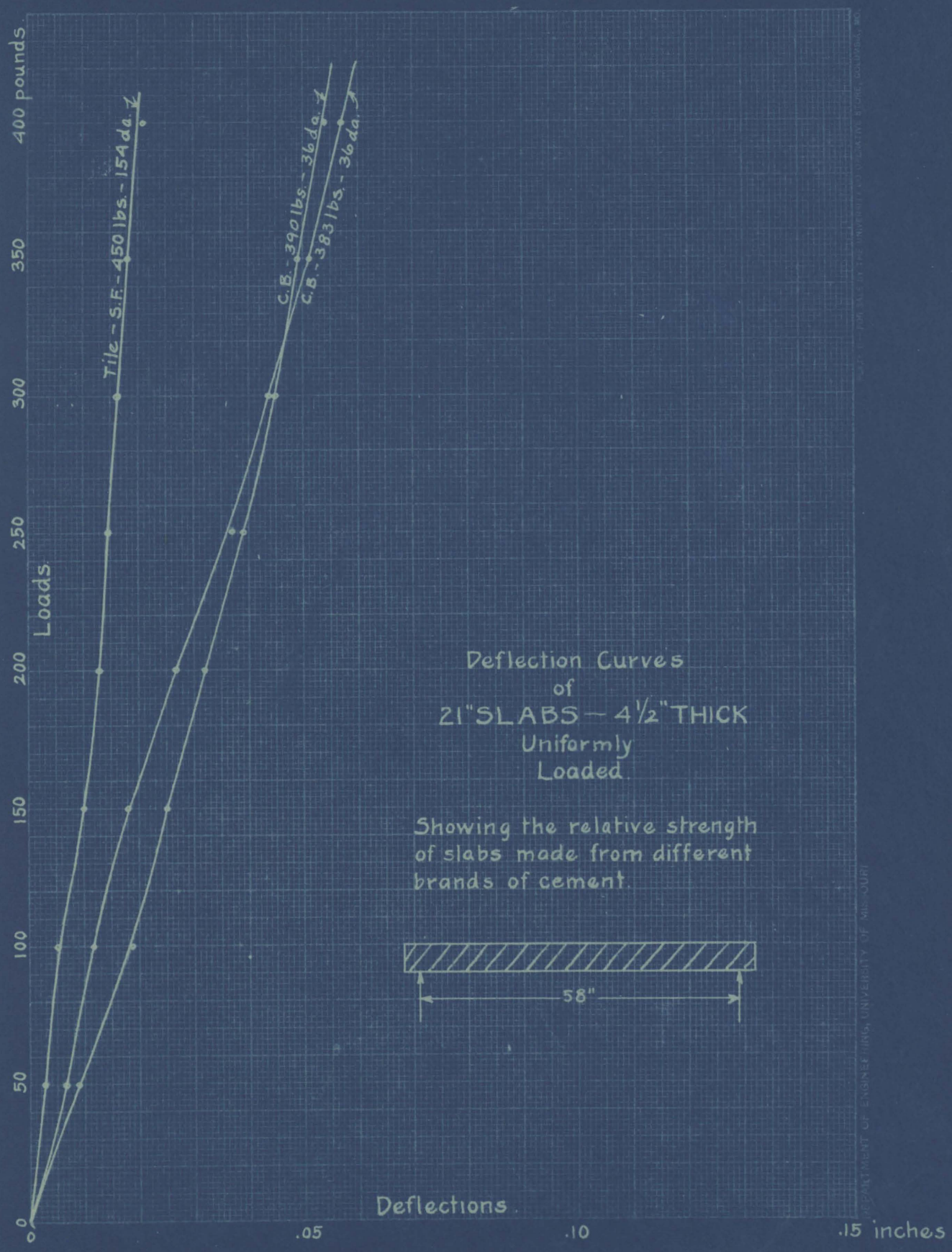
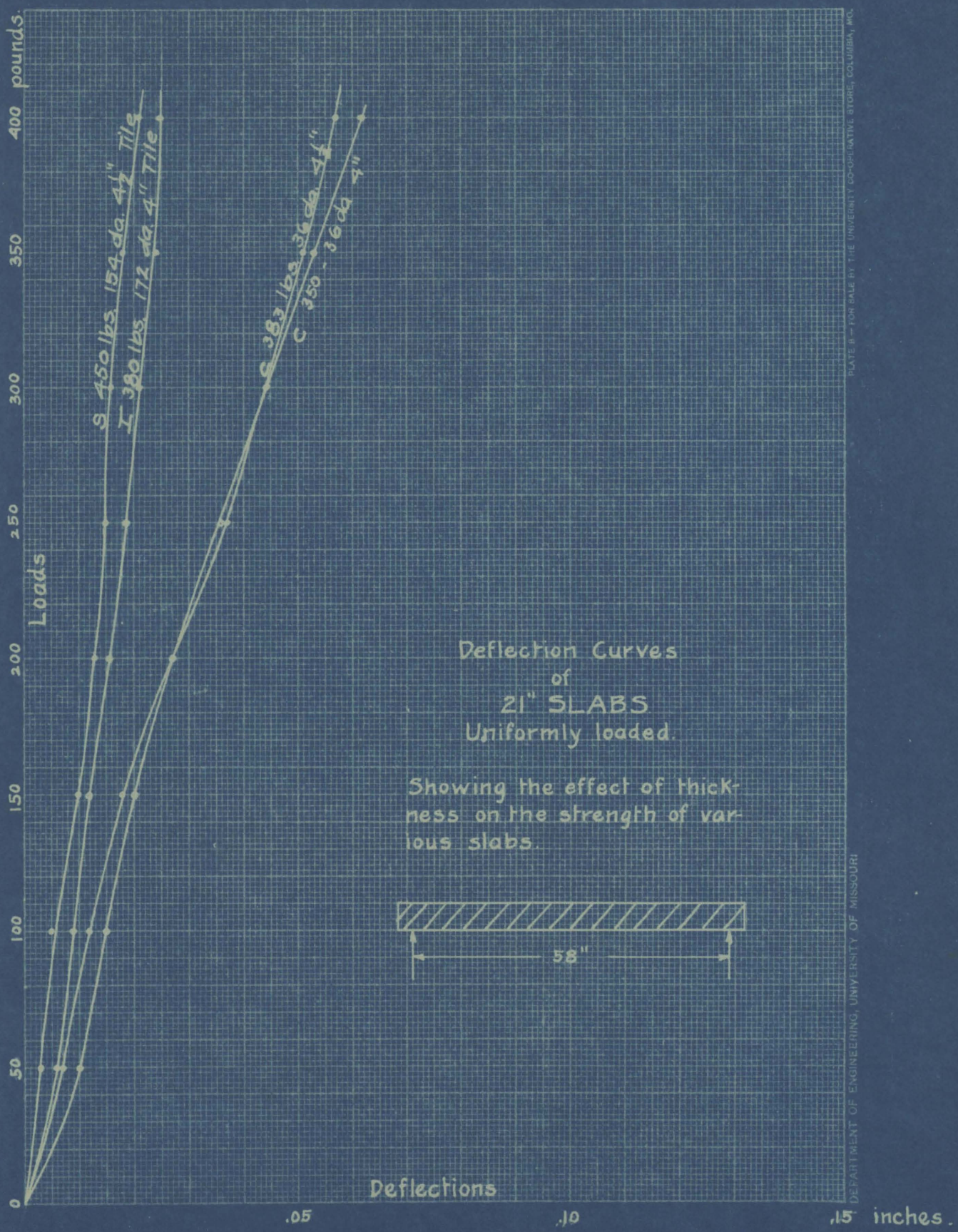

Tile - S.F. - 450 lbs. - 154 da.
C.B. - 390 lbs. - 36 da.
C.B. - 383 lbs. - 36 da.
Loads
400 pounds
350
300
250
200
150
100
50
0
Deflections
0
.05
.10
.15 inches
Deflection Curves
of
21" SLABS — 4½" THICK
Uniformly
Loaded
Showing the relative strength
of slabs made from different
brands of cement
58"

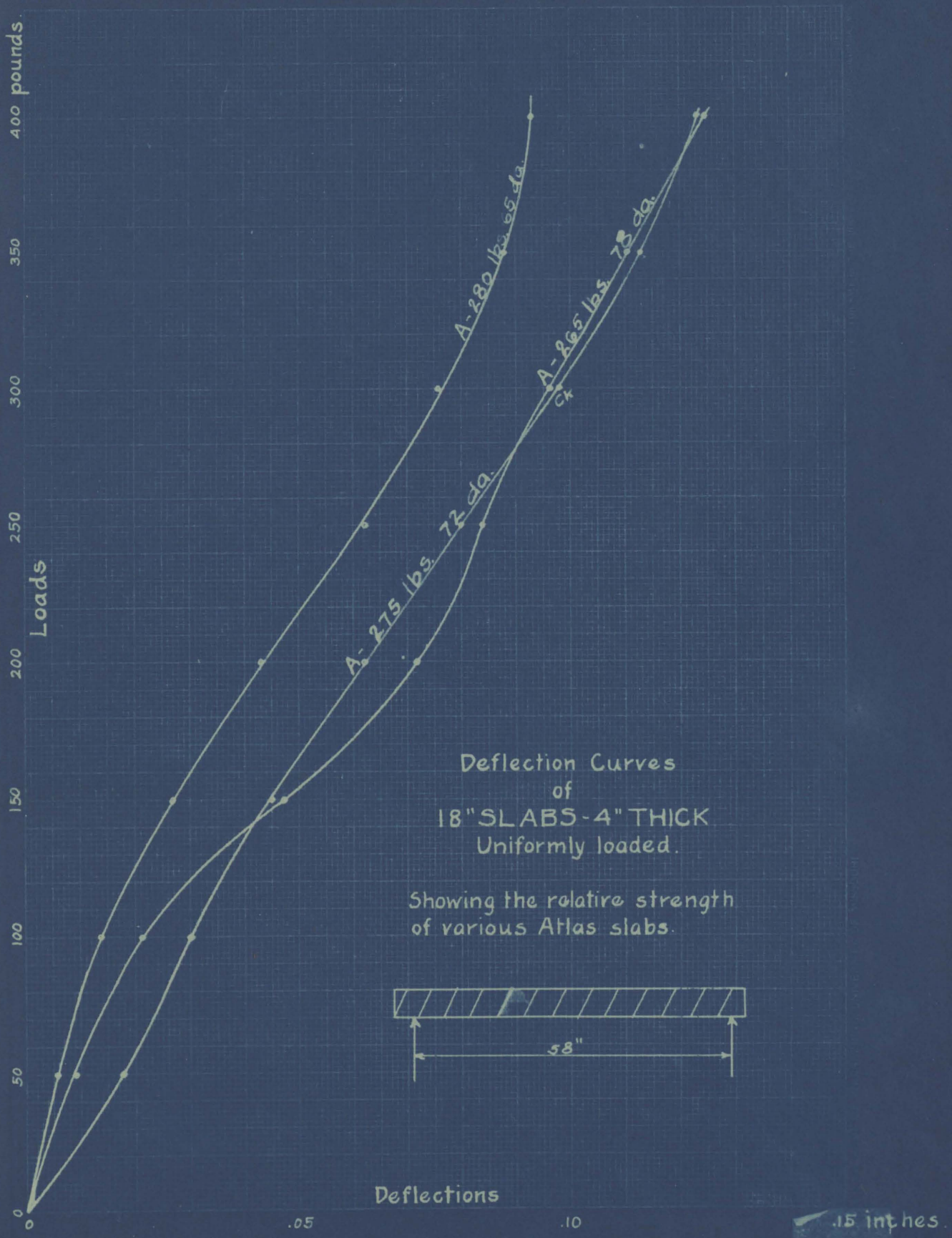
PLATE 16



Deflection Curves
of
21" SLABS
Uniformly loaded.

Showing the effect of thickness on the strength of various slabs.

PLATE 17



Deflection Curves
of
18" SLABS - 4" THICK
Uniformly loaded.

Showing the relative strength
of various Atlas slabs.

PLATE 18

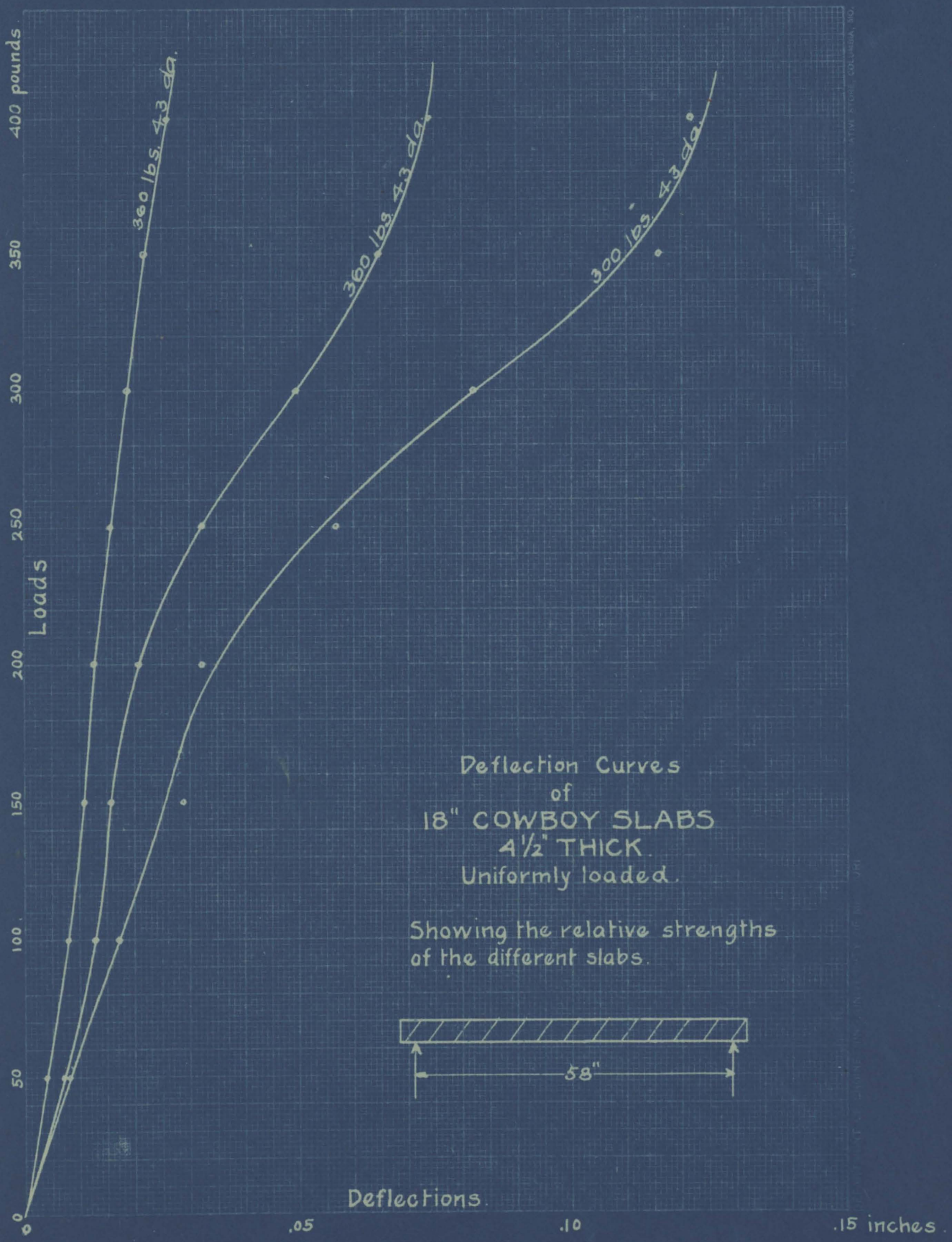

400 pounds
350
300
250
200
150
100
50
0
Loads
360 lbs. 4.3 da.
360 lbs. 4.3 da.
300 lbs. 4.3 da.
Deflection Curves
of
18" COWBOY SLABS
4½" THICK.
Uniformly loaded.
Showing the relative strengths
of the different slabs.
58"
Deflections.
0
.05
.10
.15 inches.

PLATE 19

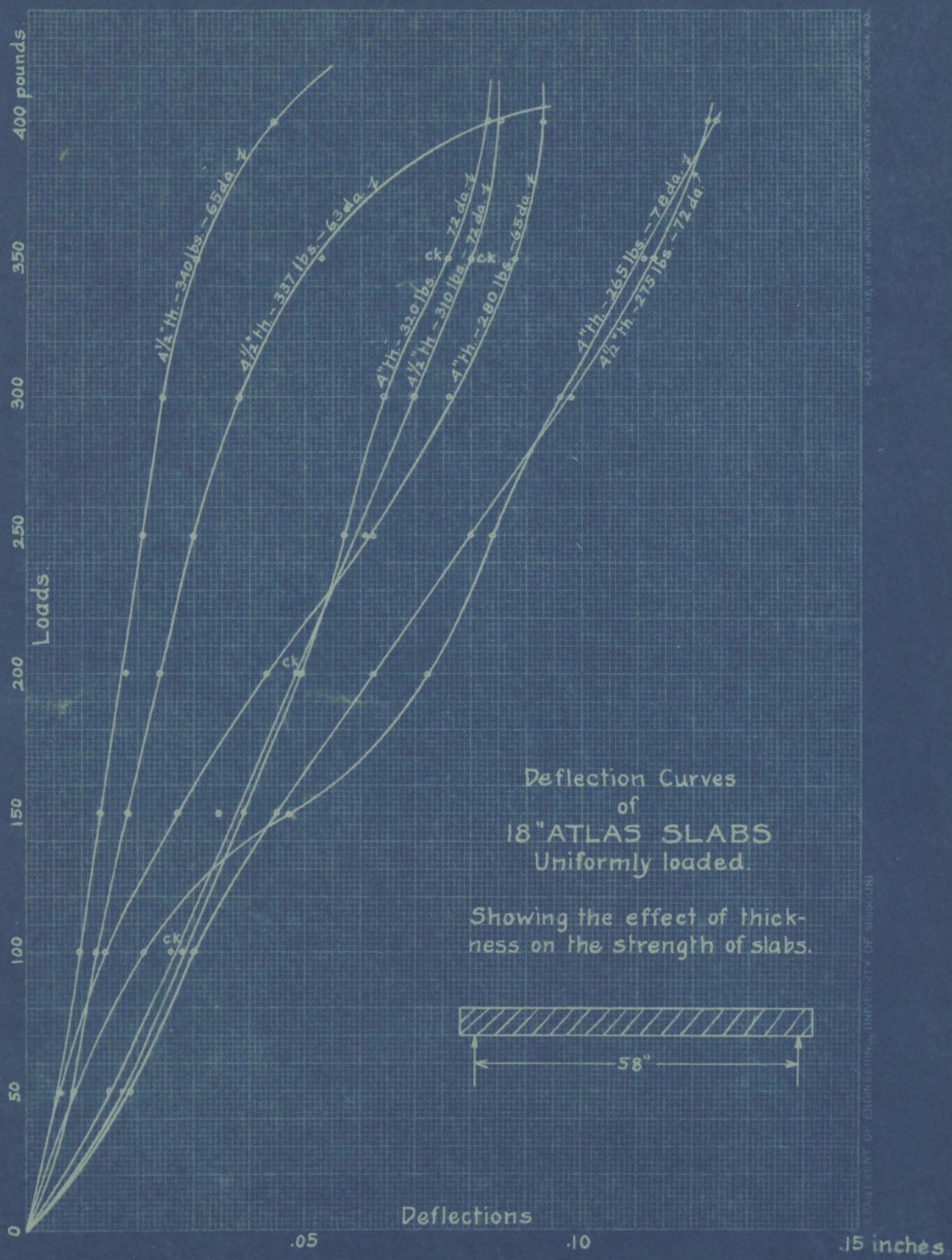

400 pounds
350
300
250
200
150
100
50
0
Loads
4½"th.-340 lbs.-65da.
4½"th.-337 lbs.-63da.
4"th.-320 lbs.-72da.
4½"th.-310 lbs.-72da.
4"th.-280 lbs.-65da.
4"th.-265 lbs.-78da.
4½"th.-275 lbs.-72da.
ck
Deflection Curves
of
18" ATLAS SLABS
Uniformly loaded.
Showing the effect of thickness on the strength of slabs.
58"
Deflections
.05
.10
.15 inches

PLATE 20

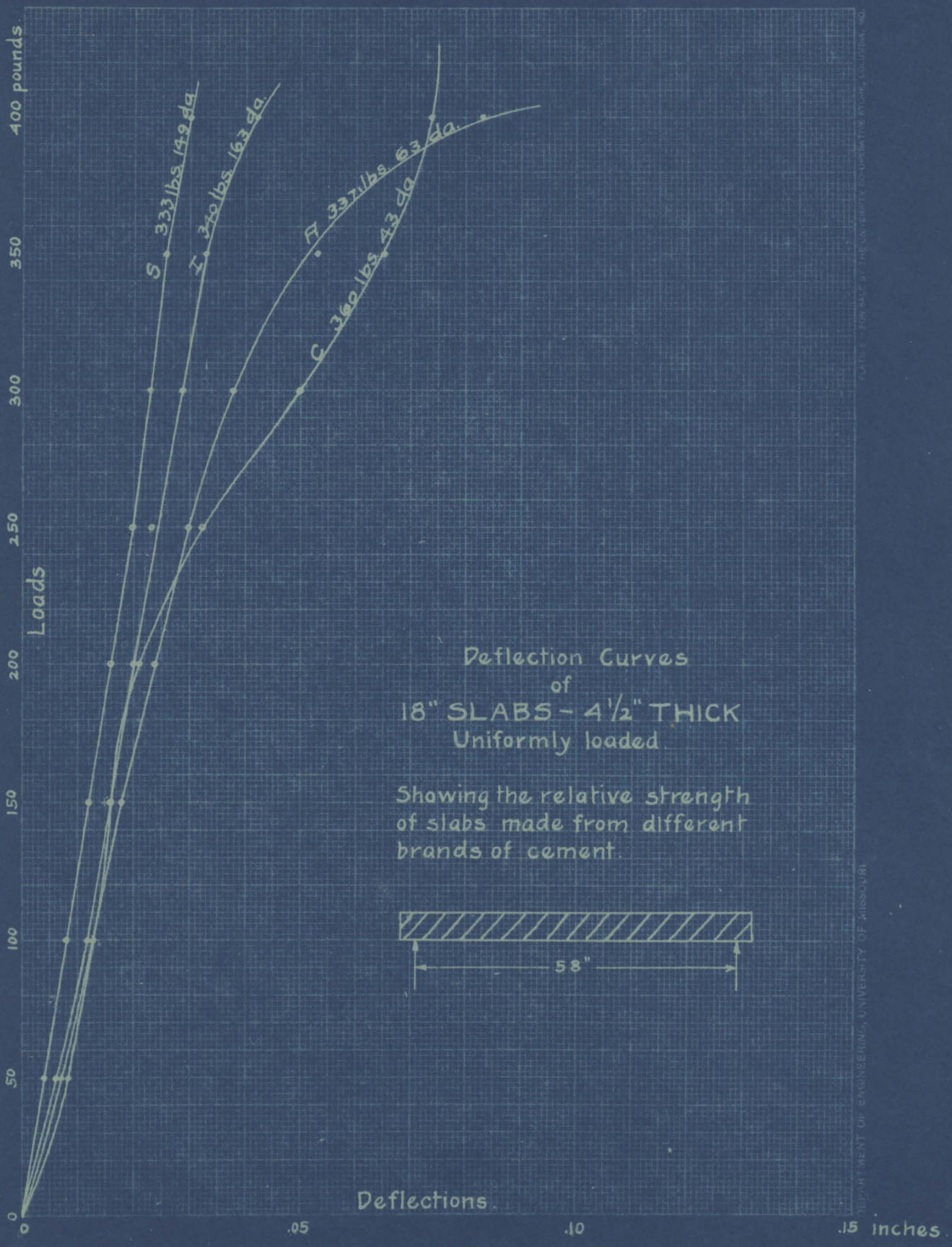
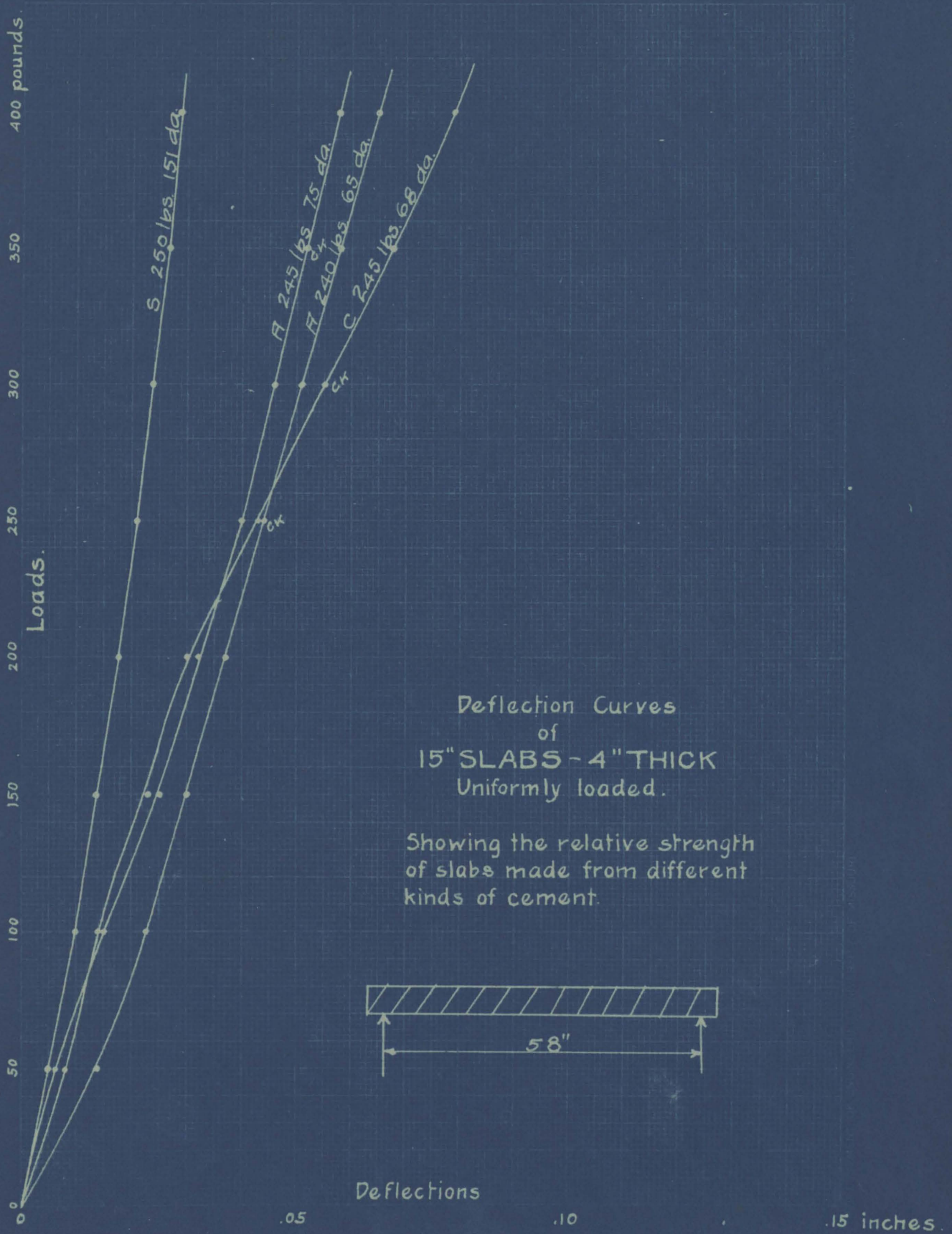

400 pounds
350
300
250
200
150
100
50
0
Loads
S 333 lbs. 149 da.
I 340 lbs. 163 da.
A 337 lbs. 63 da.
C 360 lbs. 43 da.
Deflection Curves
of
18" SLABS - 4 1/2" THICK
Uniformly loaded
Showing the relative strength
of slabs made from different
brands of cement.
58"
Deflections.
0
.05
.10
.15 inches

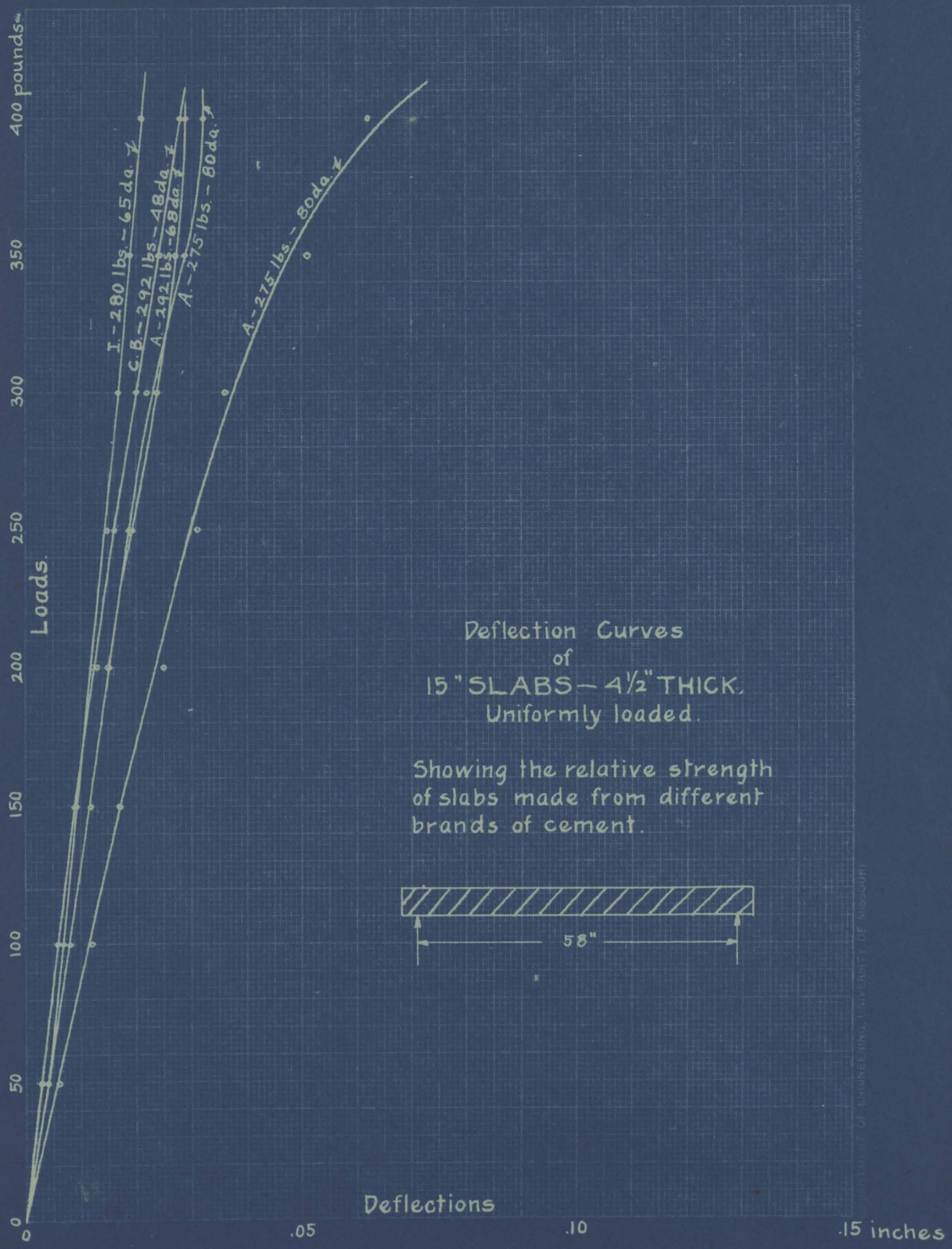
PLATE 21



Deflection Curves
of
15" SLABS - 4" THICK
Uniformly loaded.

Showing the relative strength of slabs made from different kinds of cement.

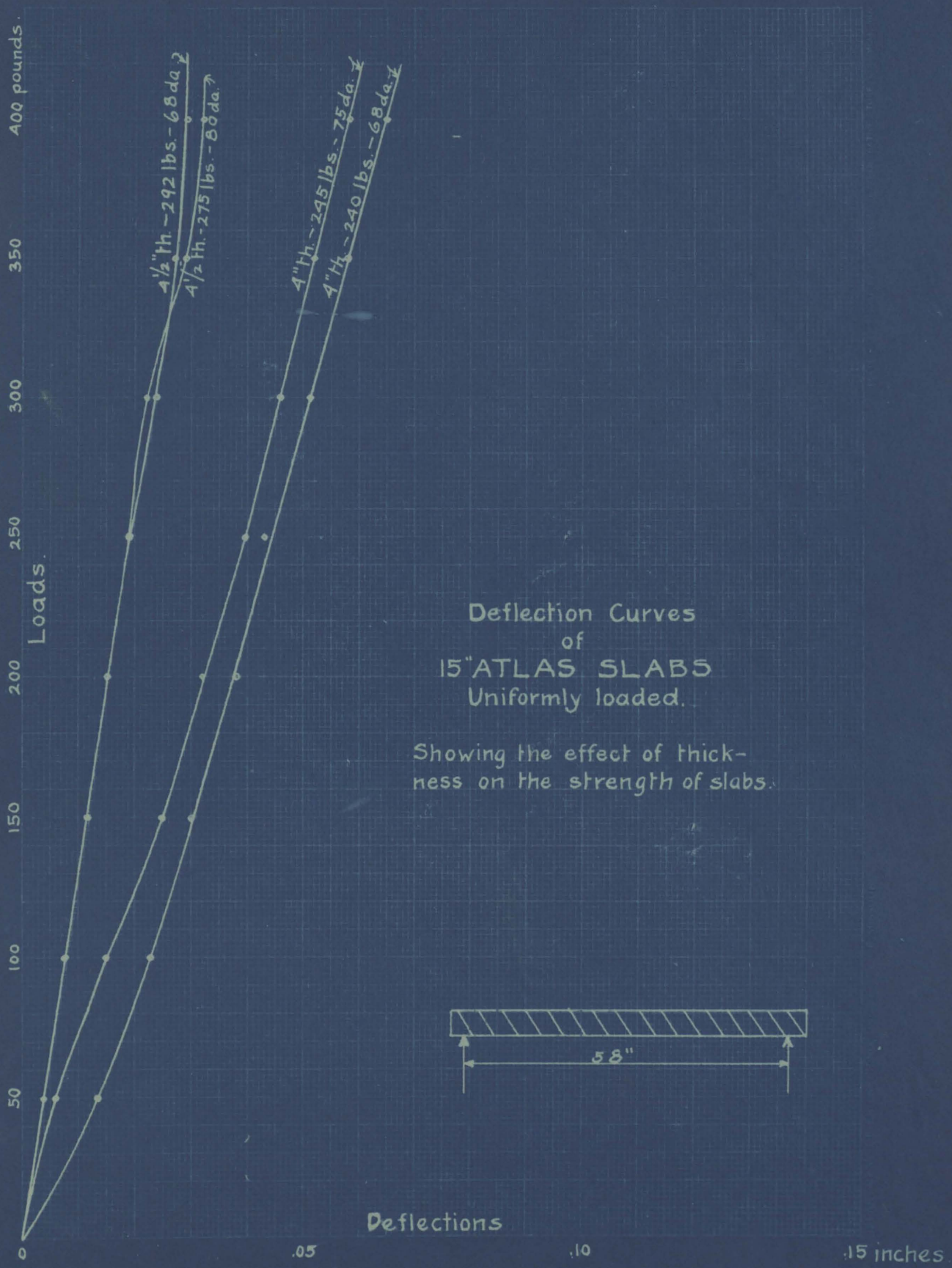
PLATE 22



Deflection Curves
of
15" SLABS — 4½" THICK.
Uniformly loaded.

Showing the relative strength of slabs made from different brands of cement.

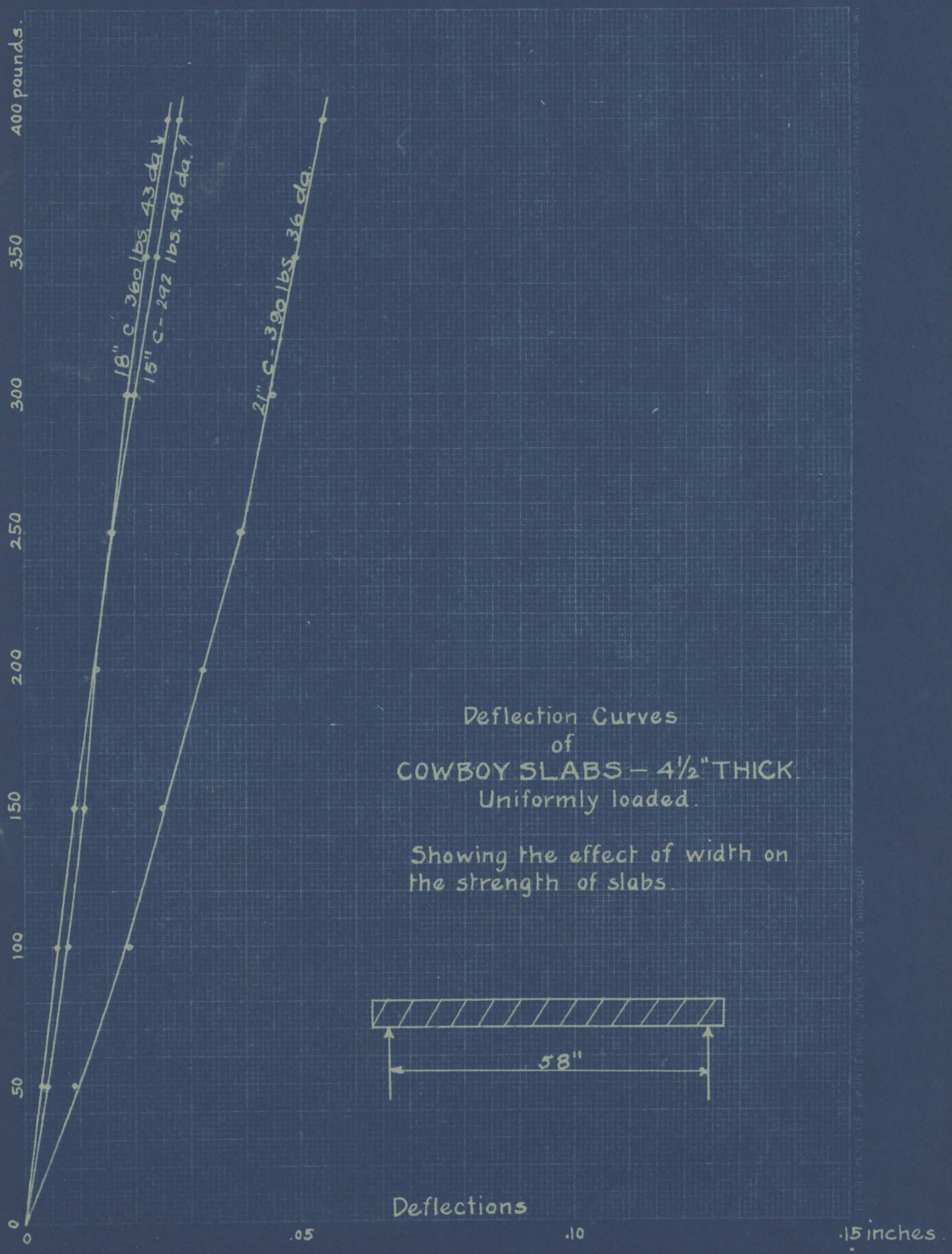
PLATE 23

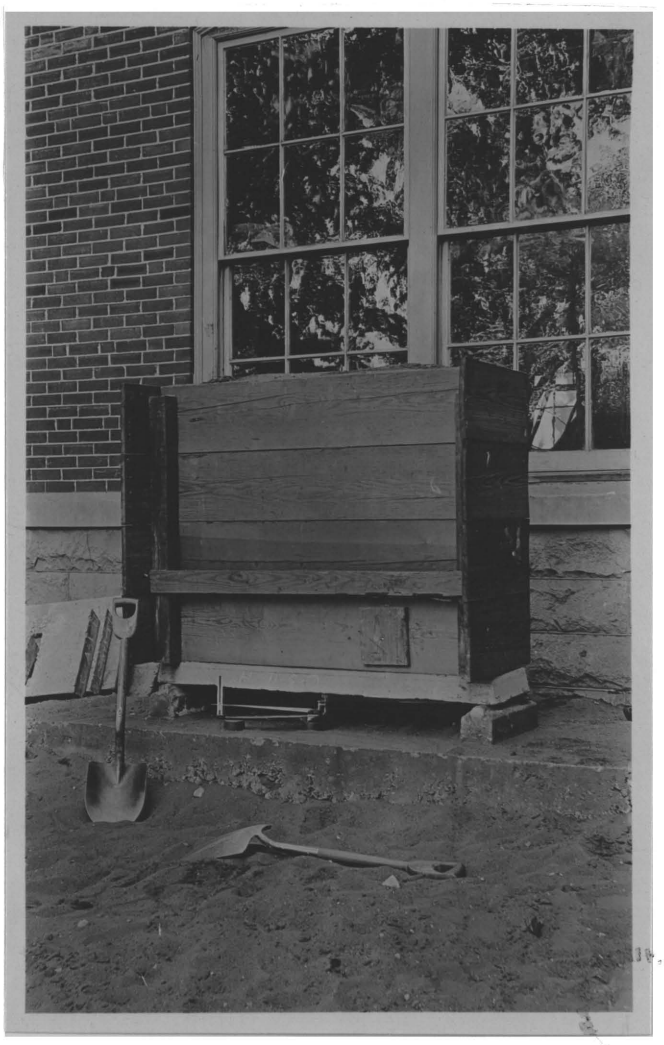


Deflection Curves
of
15" ATLAS SLABS
Uniformly loaded.

Showing the effect of thickness on the strength of slabs.

PLATE 24


400 pounds.
350
300
250
200
150
100
50
0
18" C 360 lbs. 43 da.
15" C - 292 lbs. 48 da.
21" C - 390 lbs. 36 da.
Deflection Curves
of
COWBOY SLABS – 4½" THICK.
Uniformly loaded.
Showing the effect of width on
the strength of slabs.
58"
Deflections
0
.05
.10
.15 inches.

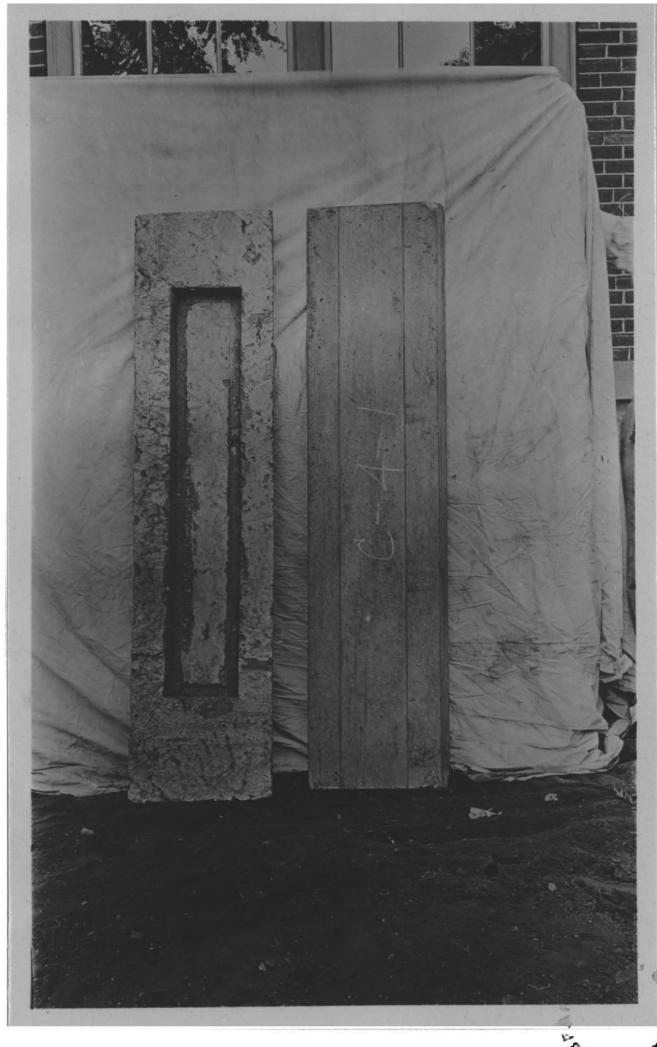


SLAB UNDER TEST LOADED WITH SAND

LOADING THE CRIB

A FEW OF THE SLABS

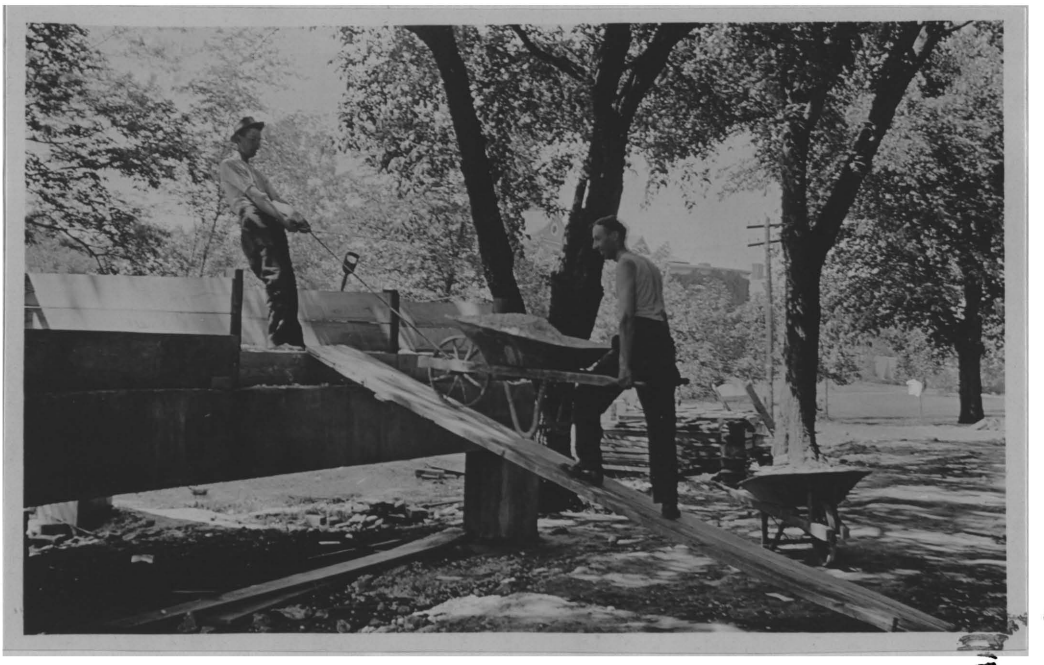
UNLOADING THE CRIB



SLABS

TESTING 12" SLABS CONCENTRATED LOAD

FORMS AND CENTERS



LOADING THE FLOOR

VIEW OF THE FLOOR FROM BENEATH

SHOWING GRADUATED SCALES