STRESSES IN A PLAIN PLATE FLAT SLAB

IN

REINFORCED CONCRETE

Thesis presented by Benjamin Gersovitz, B.Sc., B.Eng., in partial fulfillment of the requirements for the degree of Master of Engineering, at McGill University, Montreal, Que.

April 29, 1948.

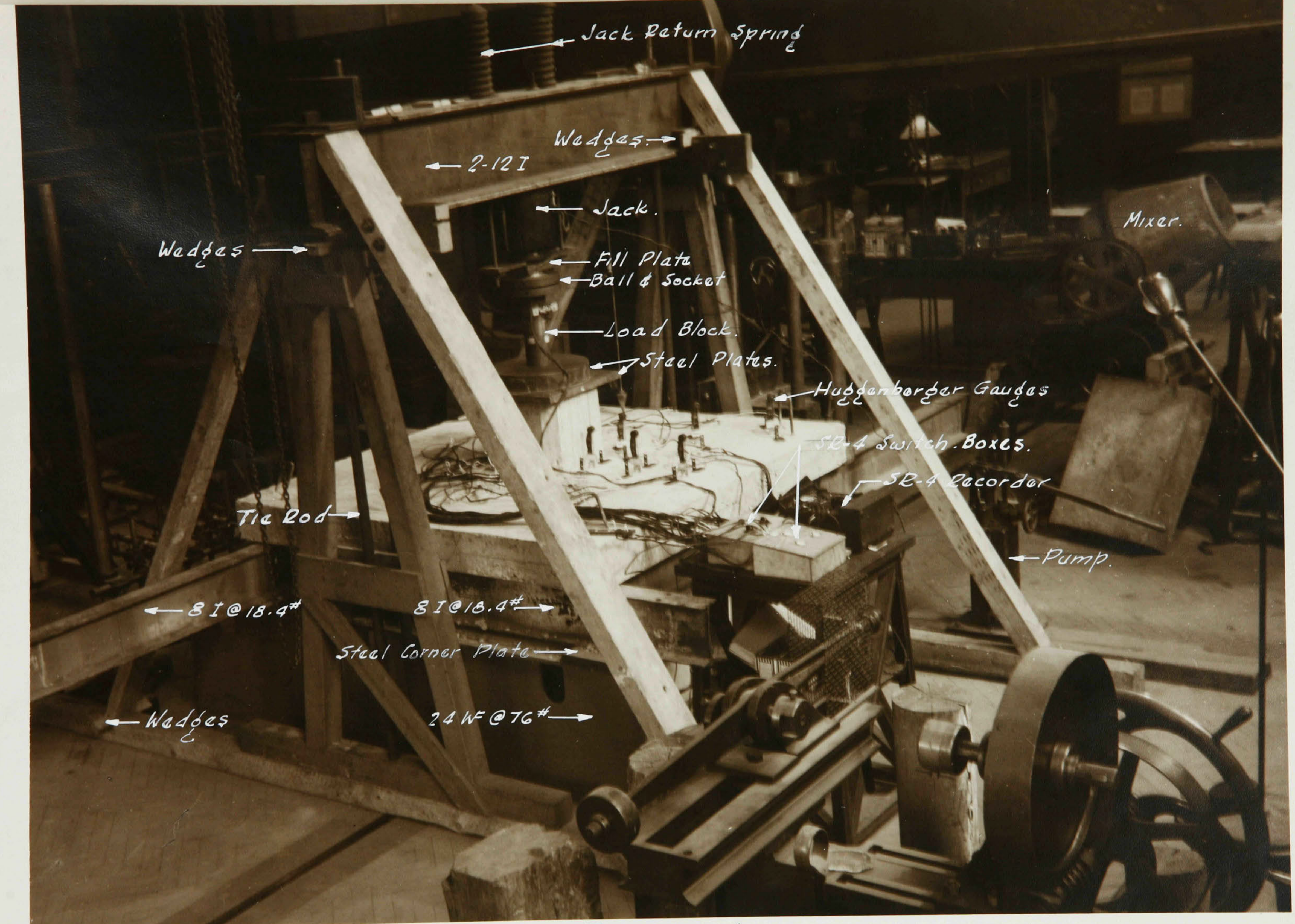

Jack Return Spring
Wedges.
2-12 I
Jack.
Wedges
Fill Plate
Ball & Socket
Load Block.
Steel Plates.
Huggenberger Gauges
SR-4 Switch. Boxes.
SR-4 Recorder
Mixer.
Tie Rod
Pump.
8 I @ 18.4#
8 I @ 18.4#
Steel Corner Plate
Wedges
24 WF @ 76#

PLATE I.

INTRODUCTION

PRELIMINARY

Where column spacing and loading have been uniform, designers almost invariably have chosen the flat slab type of structure for warehouses and manufacturing buildings of first-class construction. Its ability to carry heavy loads efficiently and the simplicity of its construction have made this type of structure economical. The lack of beams or girders has many advantages,--easier layout of sprinklers, piping and shafting; easier artificial lighting; better daytime lighting; better ventilation because of absence of pockets; less damage due to fire.

Unfortunately, the column caps and drop panels are difficult to treat architecturally. Our inability to completely analyse structurally the flat slab has resulted in a certain inflexibility in column spacing. These two disadvantages are of minor importance in most industrial buildings but in the non-industrial type of building they have so far prevented the general use of the flat slab. These buildings may be termed light-load structures,--apartment houses, hospitals, hotels, office buildings, and roofs for industrial buildings. In these the live load specified rarely exceeds seventy-five pounds per square foot.

If these two disadvantages were completely eliminated, the flat slab for use in light-load buildings would offer many advantages besides those previously mentioned. The absence of beams would permit greater freedom and flexibility in layout of rooms. Uniform thickness of slab would make possible the location of uniform height partitions. Ceilings would not have to be hung since plaster could be applied directly to the underside of the slab.

Inflexibility in column layout has been overcome somewhat by designing the flat slab as a series of continuous frames. This gives the designer sufficient information so that he can approximate the value of the critical stresses and their probable position and variation.

The problem of the column capital and drop panel has been partially solved by burying various shapes of structural steel frames in the slab over the columns. This system is patented and its cost, even for industrial buildings, is greater than the conventional method of capital and drop panel.

This still leaves the problem of using a concrete bracket at wall columns. Such a bracket, no matter how small, is unsightly.

The problem will be most easily understood by examining Tables 1 and 2. Table 1 is a summary of the load to be carried by most light-load structures. Ninety-five pounds per square foot has been taken as a representative average.

To this must be added the weight of the supporting floor structure. Table 2 is a summary of the design of a flat slab floor with square panels, but without caps and drops. Spans for these floors range from 16'-0" to 20'-0". Exterior panels have been used since they are critical.

In Table 2, part 1, the slab has been proportioned on the basis of bending moment stresses, and was designed according to the Joint Committee Code 1940. The slab thicknesses are sensible and fairly close to the minimum allowed under most codes. The average concrete stresses are low, and the steel areas result in both a practical bar size and good bar spacing. The fourteen-inch square column is about the minimum which could be used and would normally be classified as a small column. However, the unit shear v which is a measure of the diagonal tension is above 0.03f'c on the critical section.

All codes require that the maximum unit shearing stress v be equal to or less than 0.03f'c on the critical section and that this shearing force must be resisted entirely by the concrete. The reason usually advanced for this limitation is that the flat slab is a thin section and cannot adequately be reinforced against shear. Yet all codes permit the design of beams up to a shear value of 0.12f'c, provided that the shear reinforcing can be adequately anchored and placed. No mention is made which limits the depth of the member. For practical reasons, designers find it best to limit the shear value in beams to 0.06f'c. Under these circumstances the code permits that 0.03f'c be carried by the concrete and 0.03f'c be carried by the reinforcing. In Table 2, part 1, the unit shear is not above 0.06f'c. Thus, if the slab could be adequately reinforced against shear, the unit shear to be resisted would be within practical limits.

OBJECT

It was the purpose of this experiment to attempt to reinforce the slab against shearing stresses in a practical and economical manner.

It is possible to design a flat slab without cap or drops within the limits of the code. This can be accomplished in one of two ways. Keeping the columns small, the slab thickness is increased until v is 0.03f'c. Table 2, part 2, gives the slab thickness for 3000 lb. concrete. It is quite evident that this procedure results in a heavy and uneconomical structure. The second method is to proportion the slab in the usual way for bending (see part 1) but to increase the column size until the unit shearing stress is 0.03f'c. The results of this method are given in part 3. The structure is fairly economical but the column sizes are excessive. Where floor space is valuable this solution would be discarded. The ideal is to reinforce the slab against shear.

As stated previously, the problem is one of reinforcing a thin section over a large area. This makes the following considerations critical:

1. The shallow depth makes anchorage of the steel through bond with the concrete very difficult.
2. The large area and thin section means that the reinforcing is small in diameter but requires a large number of individual pieces. The shape of the reinforcing must be such as to reduce the number of individual pieces and thus simplify placing.

When the tests were first planned it was felt that the shear reinforcing, if made in some continuous shape, would overcome the anchorage problem. In this way the steel would be mechanically anchored. A continuous shape simplifies placing. Since two layers of main tension reinforcing are usually used, the continuous type could not be anchored around this steel. It was realized that this was disadvantageous but the advantages of a continuous shape outweighed this disadvantage.

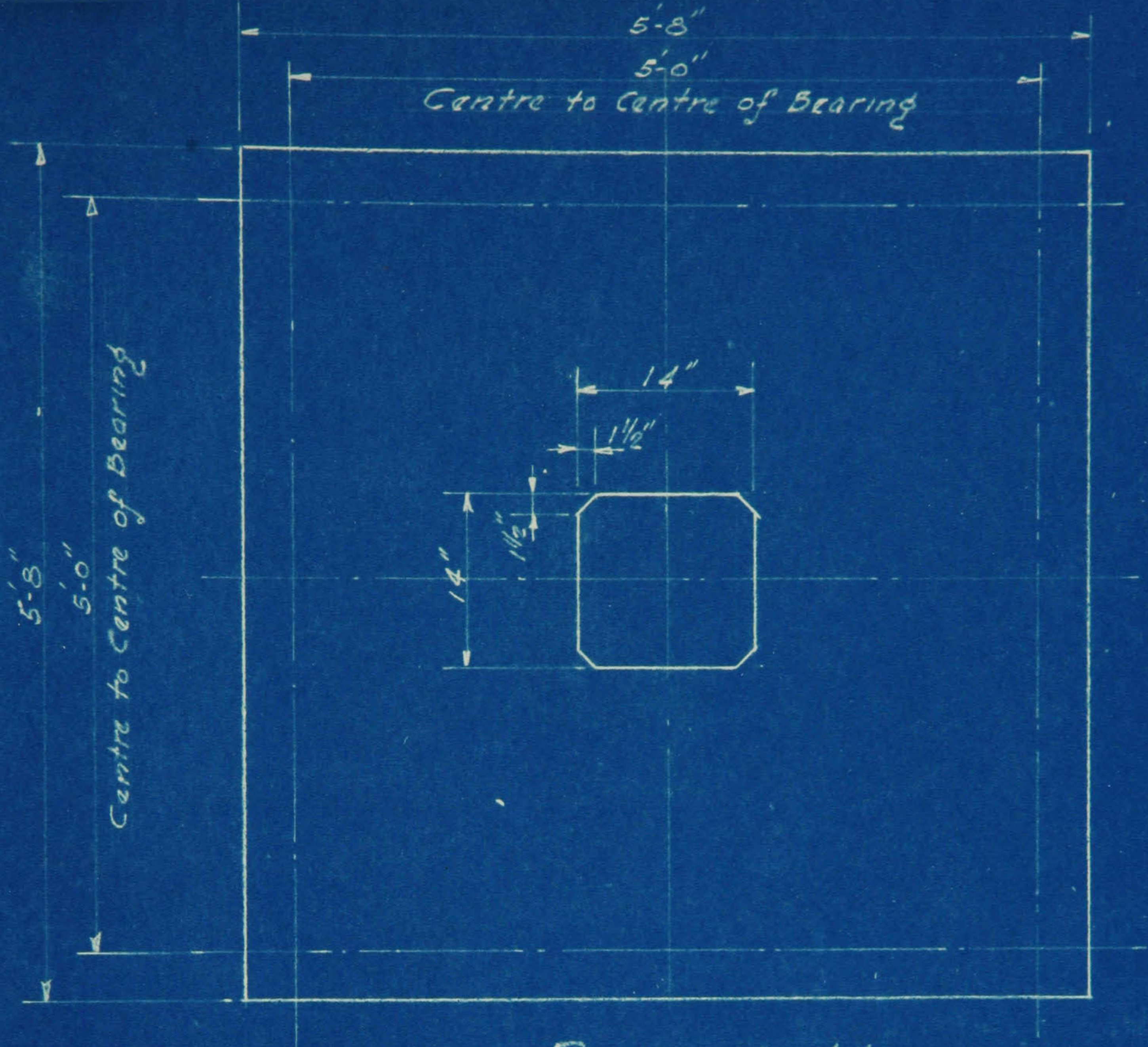
On the basis of preliminary calculations and of the magnitude of the unit shears as indicated by Table 2, part 1, it was felt that the problem of reinforcing the slab against diagonal tension might be successfully solved. It was also felt that some idea of the value of v and its distribution around the column area might be gained from the tests. Due to the difficulties of theoretical analysis of bending moments and shears and to the numerous variables in the use of concrete as a structural material, the investigation had to be essentially empirical.

TEST SLABS

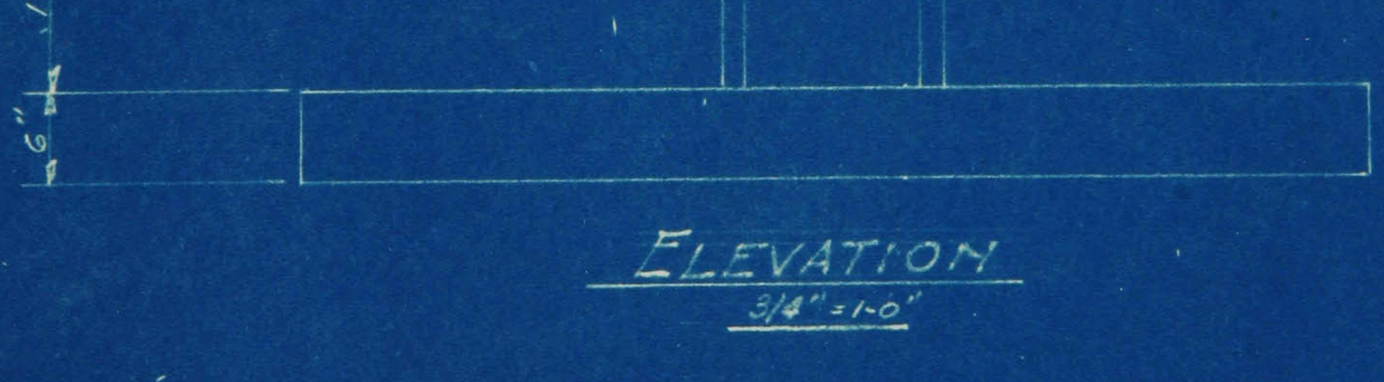
Originally four test specimens were planned. Their size and shape were limited by the testing apparatus available. The plan of the tests was to keep the slabs the same as to size, shape, concrete mix, and main reinforcing. The variable was to be the shear reinforcing. Three types of shear reinforcing were to be used, one type per slab. The fourth slab was to have no shear reinforcing and was to act as the control. By comparing the ultimate breaking load of the shear-reinforced slabs with that of the control slab, some measure of the value of the shear reinforcing would be gained.

This control slab was selected as the first test specimen. Its behaviour and failure load were to indicate any need for revision in the other slabs. Unfortunately, while testing this specimen the apparatus broke down. The delay in repairing it, accompanied by other uncertainties, made the results from this test valueless and it was necessary to build another control specimen as the final slab. The results of this first slab (Slab A) have therefore not been presented in this thesis.

Preliminary calculations were based on 3000 lb.



PLAN - 3/4"=1'-0"



ELEVATION
3/4"=1'-0"

NOTE:- Dimensions of all slabs same
as shown above
For view of forms see Plates 6 to 10

SLAB SHAPE & DIMENSIONS.

FIGURE 1.

concrete at time of testing. Due to the length of time required to set up the slab and apparatus about 3800 lb. concrete resulted.

The general shape of all slabs is shown in Figure 1. The column was made 14 inches square and 1'-2" above the slab. Each slab was 5'-8" square and 6 inches thick. Four lifting hooks, one per corner, were cast in the slab to facilitate handling.

Table 2, part 1, suggests that a six-inch slab is about the minimum thickness which can be used and hence is the most critical thickness for shear. If this thickness could be successfully reinforced, then thicker slabs would present no difficulty. For this reason the 6-inch slab was used throughout.

Based on the following stresses:

$f'c$ = 3000 p.s.i. at time of testing;

$fc = .45f'c$

fs = 20,000 p.s.i.

po = 0.0136

d = 5 inches

effective width = 5'-0" = 60"

the concrete will develop 0.0136 x 5 x 60 = 4.08 sq. in. = 13 + 5/8 round. Fifteen 5/8 round bars spaced at 4 1/4" centre to centre were used for main reinforcing in all slabs. The ends of all bars were hooked to supply adequate anchorage. These were very carefully spaced and tied in place. The

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s 9 and 10) A continuous N-shaped
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(b) The intensity of shear v was calculated by the usual formula $v = \frac{V}{bjd}$ where

V = total shear

b = effective width, i.e., the circumference of the circle.

grillage was supported on sheet metal chairs which assured a 3/4" concrete cover over the bottom layer of bars.

The column was reinforced with six 5/8 round vertical bars and 1/4 round spiral at 1 1/2" centre to centre, coiled to an 11-inch diameter.

Three types of shear reinforcement were used, one type per slab.

Type 1. (See Plate 5) A continuous U-shaped stirrup placed in concentric circles about the column. This is simply an extension of the ordinary stirrup used in beams.

Type 2. (See Plates 7 and 8) A continuous helix placed in concentric circles about the column forming a series of toroids.

Type 3. (See Plates 9 and 10) A continuous N-shaped stirrup placed radially.

The quantity and spacing of the reinforcing were obtained by making certain approximate assumptions.

(a) The intensity of shear v was the same for all points equidistant from the centre of the column, i.e., points on the circumference of a circle whose centre coincided with that of the column.

(b) The intensity of shear v was calculated by the usual formula $v = \frac{V}{bjd}$ where

V = total shear

b = effective width, i.e., the circumference of the circle.

j = ratio of distance between centroid of compression and centroid of tension to the depth d. Assumed constant @ 7/8 d.

d = depth from compression face of slab to centre of lower layer of main tensile steel.

(c) The total shear V remained constant.

(d) The critical plane of shear occurred at a distance $\frac{c}{2}$ + 2t - 3" where

c = diameter of a circle whose area equals the area of the column.

t = thickness of the slab.

The slabs were designed to resist 0.06f'c; 0.03f'c of the shear to be carried by the concrete and 0.03f'c by the steel.

With f'c = 3000 lb. at time of testing, then 0.06f'c = 180 p.s.i., using 14" x 14" column equivalent diameter c = 15.8". The critical diameter = 15.8 + 12 - 3 = 24.8" and working load = 180 x 0.875 x 5 x 24.8π = 61,300 lb.

The assumed shear variation is shown in Figure 2. For simplicity of calculation this area was assumed triangular.

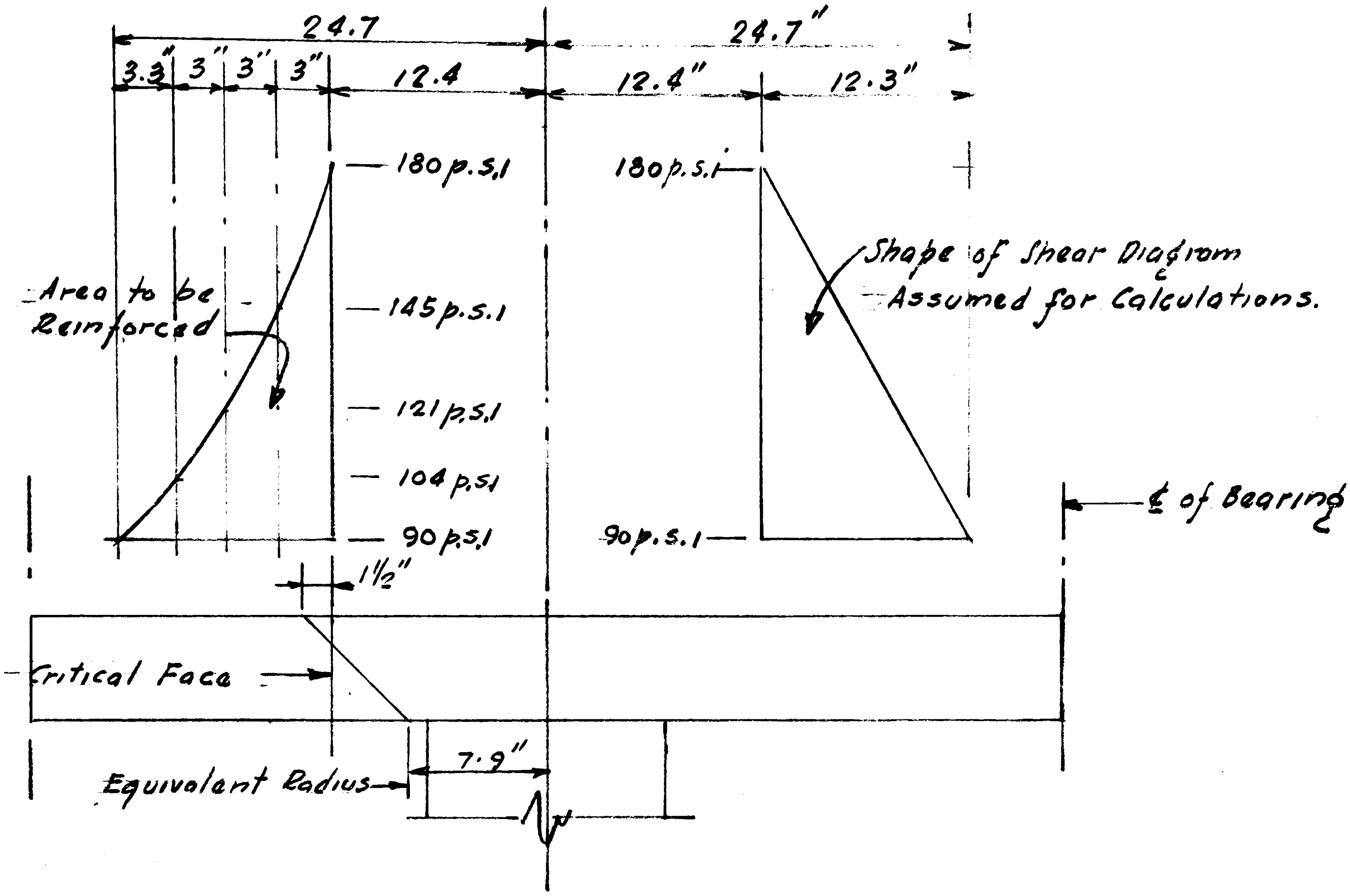


FIGURE 2

TYPE 1 and 2 The stirrup spacing was calculated in the usual way by dividing the triangle into three equal areas and placing the concentric circles of stirrups on the centre of gravity of these areas. The total shear force which each concentric ring of stirrups resisted was equal to the shear area from the diagram multiplied by 2π times the distance from the centre line of the column to the centre line of the area.

1st Area

$$\left\{ \frac{74 \times 2.2}{2} \left(12.4 + \frac{2.2}{2}\right) + 16 \times \frac{2.2}{2} \left(12.4 + \frac{2.2}{3}\right) \right\} 2\pi = 15{,}300 \text{ lb.}$$

2nd Area

$$\left\{52 \times 3 \left(14.6 + \frac{3.0}{2}\right) + \frac{22 \times 3.0}{2}\left(14.6 + \frac{3.0}{3}\right)\right\} 2\pi = 19{,}000 \text{ lb.}$$

3rd Area

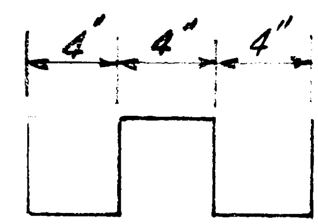
$$\frac{7.1 \times 52}{2}\left(17.6 + \frac{7.1}{3}\right) 2\pi \doteq 23{,}200 \text{ lb.}$$

Value of 1/4 round stirrup - (1 vertical leg) f_v = 16,000 p.s.i.

= 0.05 x 16,000 = 800 lb.

TYPE 1

Sheer	No. of Vert. Legs Req'd.	Circumference	Spacing
15300	24	84"	4"
19000	24	100"	4"
23200	30	125"	4"



In the case of the helix, one loop was considered to be equivalent to two vertical legs of the U-shaped stirrup. Hence in the portion closest to the critical face ten loops were required, which meant a pitch of $\frac{84}{10}$ = 8.4". For a 3-inch diameter helix this was far too great, hence a pitch of 7/8 d was chosen as the maximum.

7/8 d = 2.6" say 3"

TYPE 2

Shear	Pitch	No. of Turns
15300	3"	28
19000	3"	33
23200	3"	42

TYPE 3 For the radial stirrups the base of the triangular shear area was divided into three equal parts. The shear of each ring is given below.

Area 1 = 27,600 lb.

Area 2 = 21,200 lb.

Area 3 = 8,500 lb.

Value of 1 vertical leg and 1 diagonal leg =

$$(1 + 1.41)\ 800 = 1930 \text{ lb.}$$

$$\frac{4.1}{4.75} \times 1930 = 1660 \text{ lb.}$$

hence the number of radials required = $\frac{27600}{1660} = 17$

The above arrangement of stirrups did not give uniform distribution of steel as in the concentric types, but unless the constant spacing was maintained the slope of the diagonal leg could not be maintained constant. This would have resulted in practical bending difficulties.

The spacing indicated by the approximate calculations shown above were modified in the test specimens as follows:

Type 1 On the basis of the failure cracks of Slab A, the rings of stirrups were moved closer to the column.

Type 2 Since Slab B showed little increase in shear strength, it was decided to increase the number of helical rings and cover the slab area completely.

Type 3 The seventeen radials were increased to twenty-four. This gave a closer spacing between the outer portion of adjacent radials.

GAUGE POSITIONS

The choice of gauge positions was based on the following considerations:

1. Tension Steel (See Figure 3)

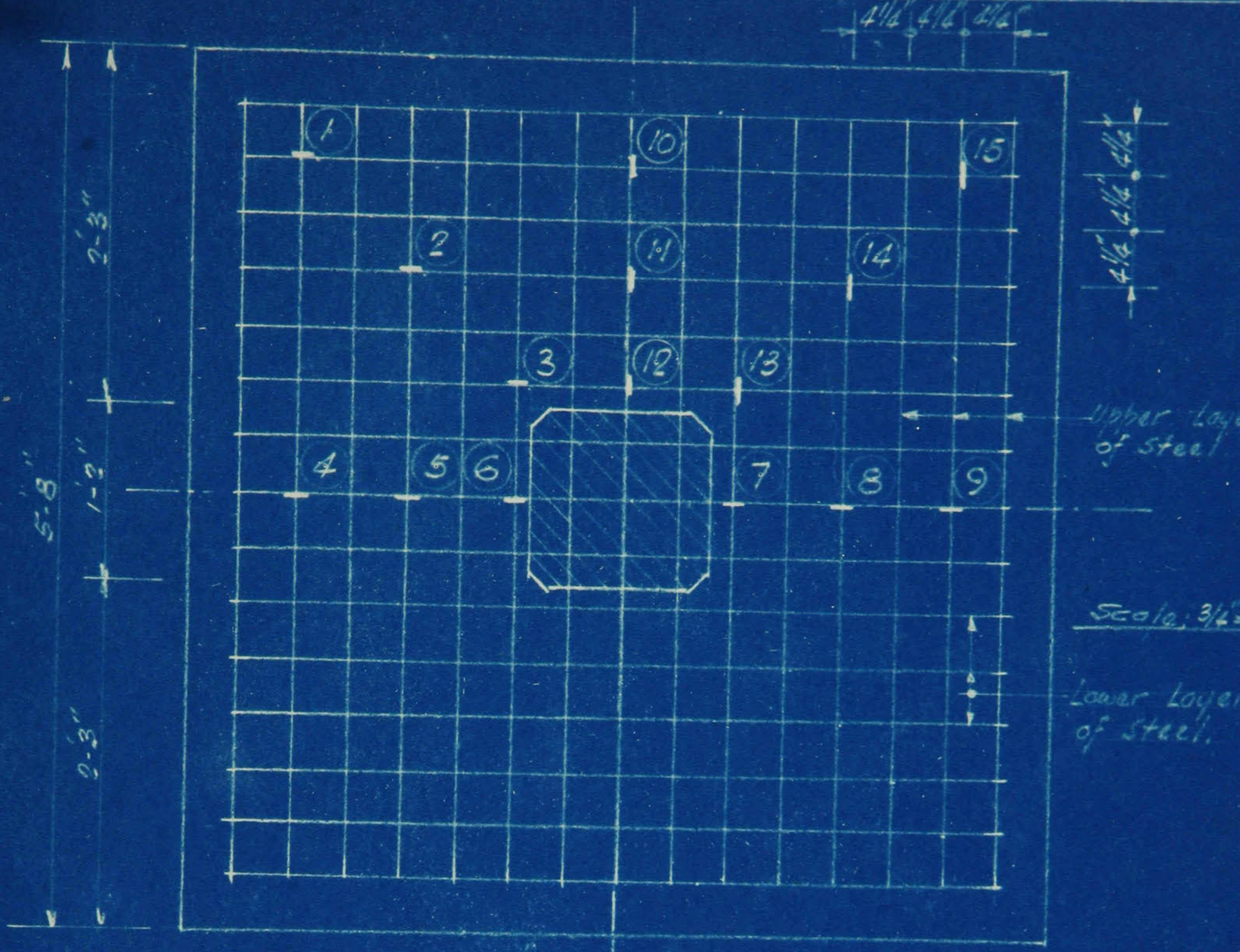
   On the assumption that the shear reinforcing would be effective, then variation of the bending moment along the slab could be used as a measure of the shear, i.e., $\frac{dM}{dx} = V$ and $v = \frac{V}{bjd}$. By placing the gauges on the diameters and on the diagonal a complete picture of the variation of the bending moment along the slab and along the diagonal would be obtained. Enough gauges had to be placed in similar positions to check on each other.

2. Shear Reinforcing (See Figures 4A, 4B, 4C)

   To obtain some idea of the distribution and magnitude of stress in the shear reinforcing, the gauges were placed along two diameters and one diagonal.

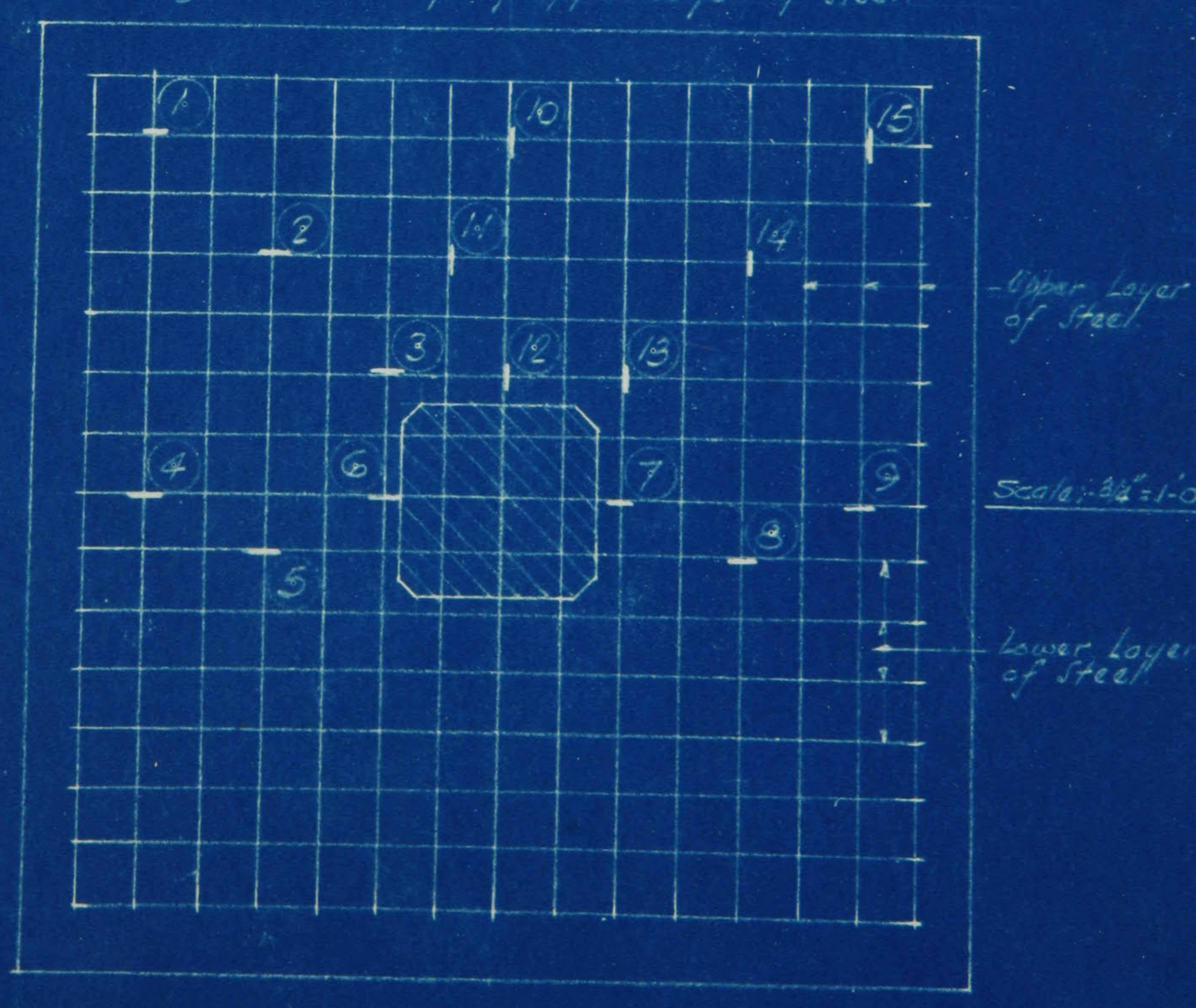
3. Compression Face of Concrete (See Figure 5)

   Gauges were placed on the compression side of the slab to supply some information on the compressive stresses in the concrete. Since only six Huggenbergers were available, three were placed on a



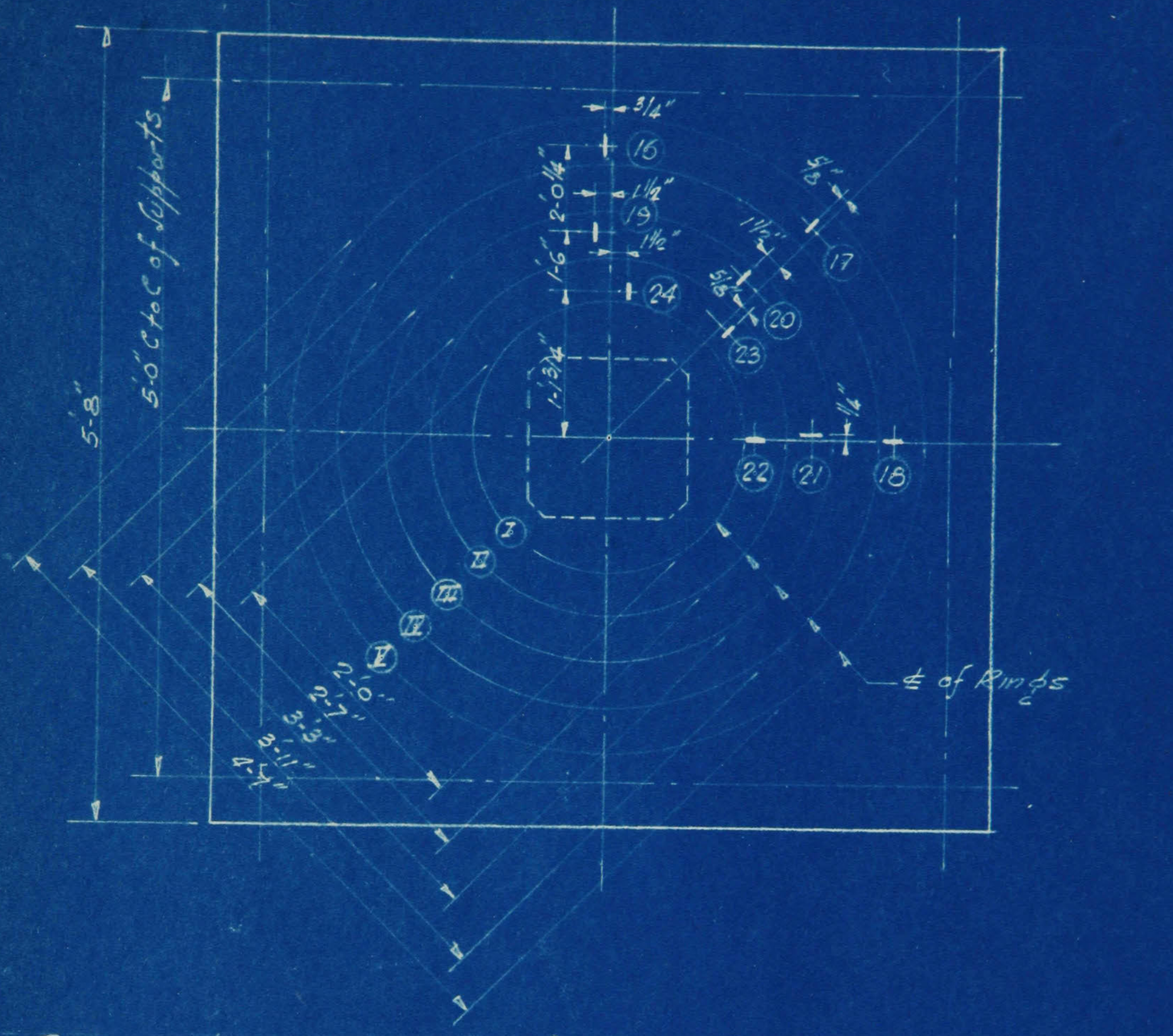
LOCATION OF SR-4 GAUGES ON TENSION STEEL - SLABS B&C

NOTE:- Gauges 1 to 9 on bottom of lower layer of steel.
Gauges 10 to 15 on top of upper layer of steel.



LOCATION OF SR-4 GAUGES ON TENSION STEEL - SLABS D&E

FIGURE 3



GAUGE LOCATIONS ON SHEAR REINFORCING - SLAB C

3/4" = 1'-0"

SHEAR REINFORCING

Coils Wound to 3 1/2" Outside Diam.

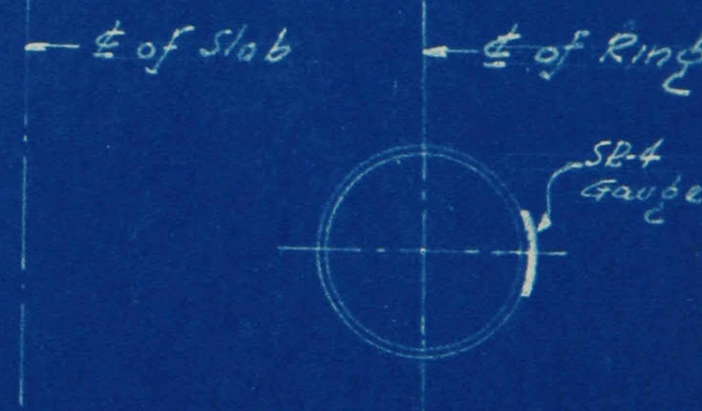
Ring		No of Coils
I	—	27
II	—	32
III	—	41
IV	—	49
V	—	56

Pitch - 3" ± 1/4"

Splices Made by Lapping Two Turns.

All Laps Well Wired.

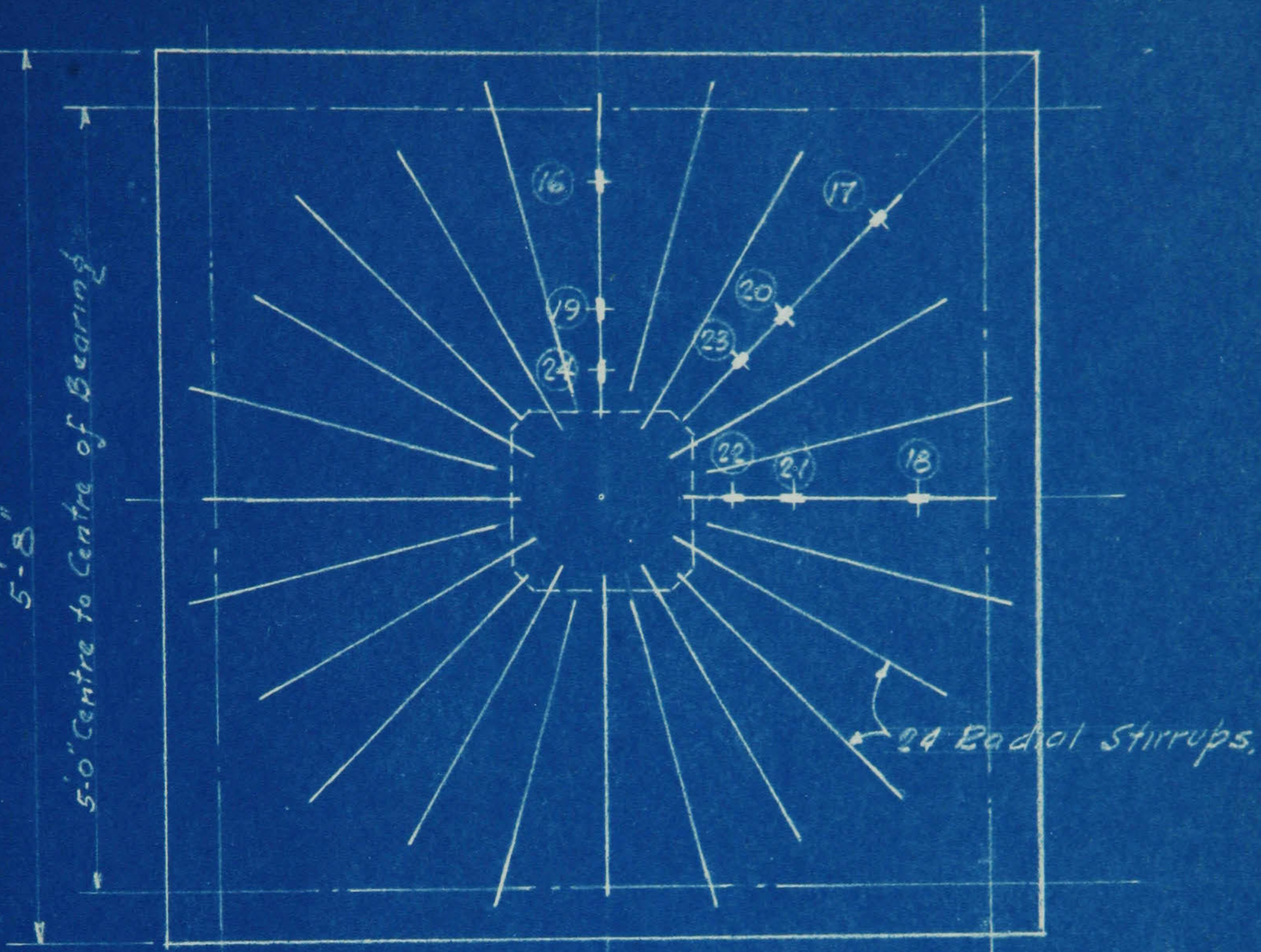
All Steel - 1/4 ϕ



LOCATION OF SR-4 GAUGE

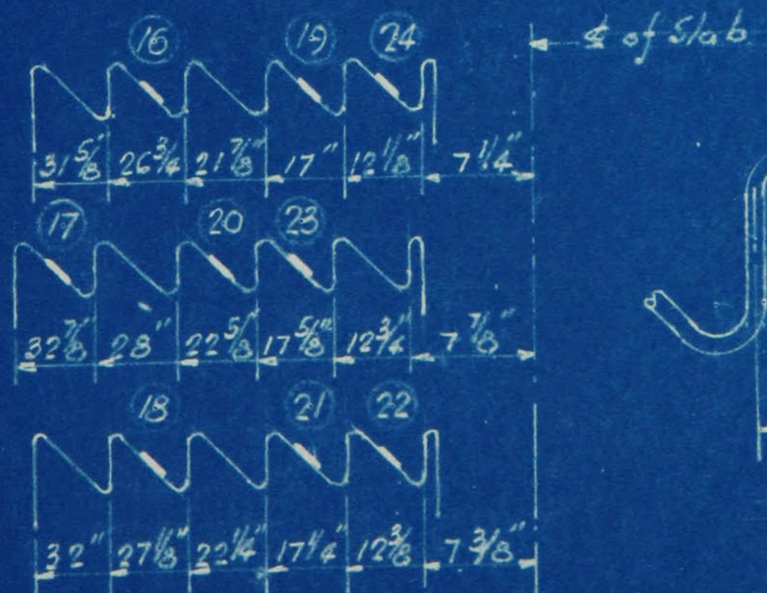
NOTE: - See Plates 7 & 8 for Views of Shear Reinforcing in Place

FIGURE 4B

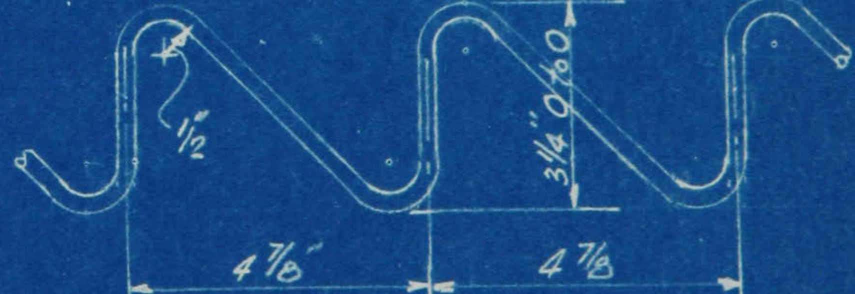


GAUGE LOCATIONS ON SHEAR REINFORCING - SLAB D

3/4" = 1'-0"



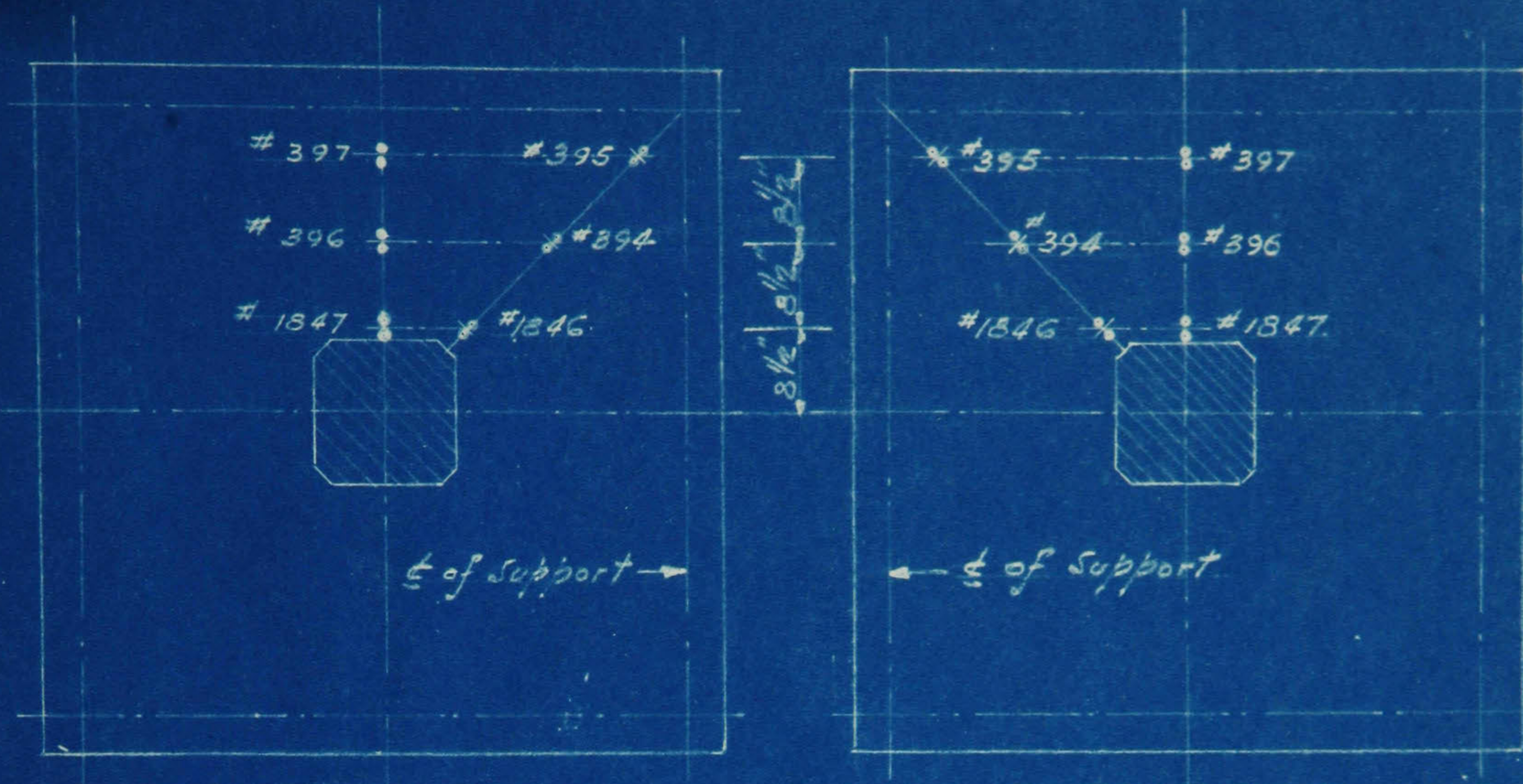
GAUGE LOCATIONS



All Stirrups - 1/4 φ

NOTE:- See Plates 9 & 10 for Views of Shear Reinforcing in Place

FIGURE 4c

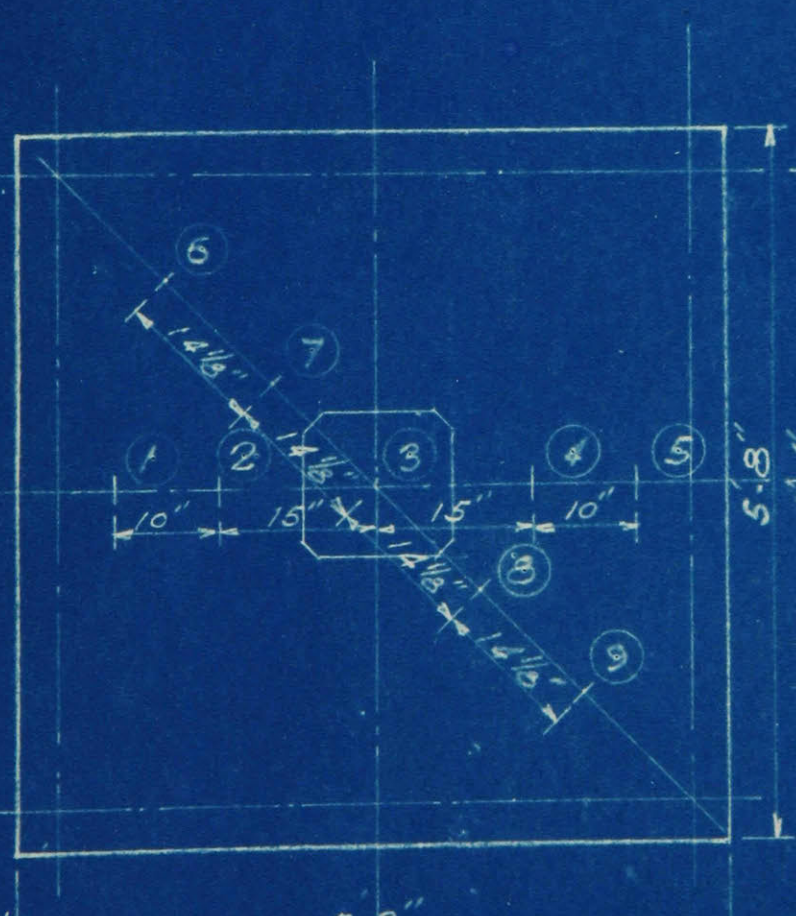


SLAB B.   SLAB C-D-E.

LOCATION OF HUGGENBERGER GAUGES ON CONCRETE

1/2" = 1'-0"

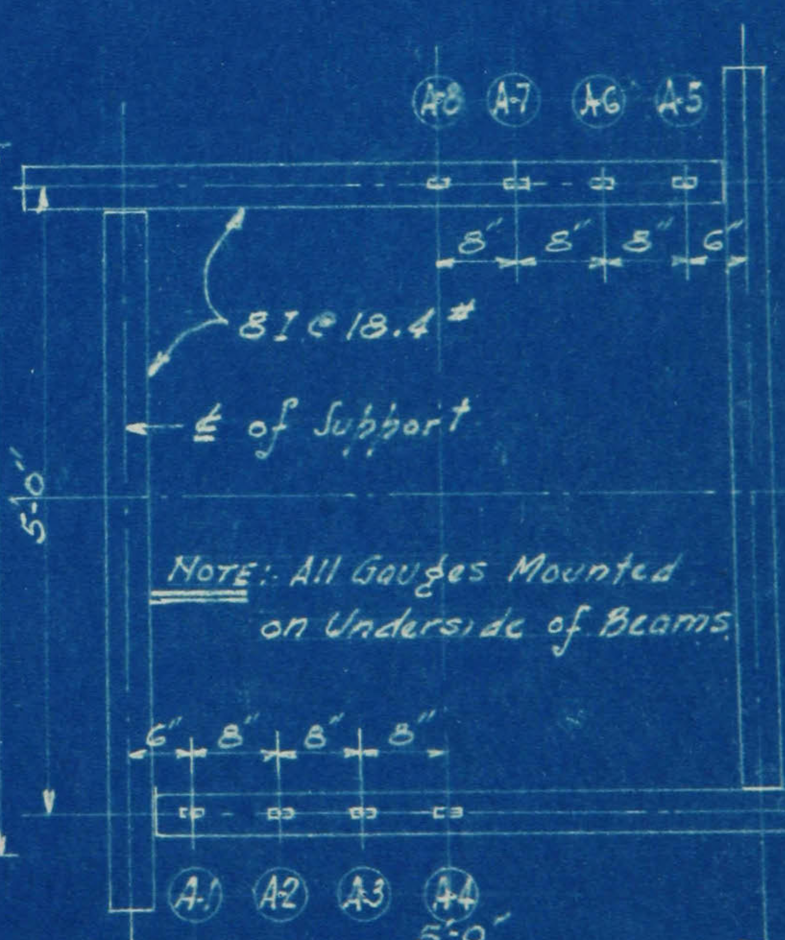
FIGURE 5



LOCATION OF DEFLECTION GAUGES

1/2" = 1'-0"

FIGURE 6



LOCATION OF GAUGES A' TO A

1/2" = 1'-0"

FIGURE 7

diagonal and three on a diameter with gauge centre-lines directly over similar gauge positions on the tension steel.

4. Deflection Gauges (See Figure 6)

These gauges were used as an overall check on the action of the slab under load. Nine were placed on the underside of the slab,--four along one diameter, four along one diagonal, and one at the centre.

5. Gauges A-1 to A-8 (See Figure 7)

SR-4 Gauges were mounted on the underside of two of the 8 I @ 18.4 lb. These were mounted for the purpose of indicating the distribution of the reactions along the edge of the slab. Readings were taken on these gauges but their values were not used in the thesis. The gauge values are nonetheless presented since they may be of some value in future work.

The following is a schedule giving the dates on which the various slabs were poured and tested.

CALENDAR
1947

SLAB B

Poured	June 16	
Test Run 1	June 27	10 A.M.
Test Run 2	June 27	12 Noon
Test Run 3	June 27	5.15 P.M.
Test Run 4	July 24	

SLAB C

Poured	Aug. 21	
Test Run 1	Aug. 29	2 - 4 P.M.
Test Run 2	Aug. 29	4.10 - 6.25 P.M.
Test Run 3	Aug. 29	9 - 11 P.M.
Test Run 4	Sept. 2	2.40 - 5.30 P.M.

SLAB D

Poured	Sept. 20	
Test Run 1	Sept. 28	3.45 - 6.40 P.M.
Test Run 2	Sept. 28	7.30 - 9.45 P.M.
Test Run 3	Sept. 28	9.50 - 12.40 P.M.
Test Run 4	Oct. 1	7.15 - 10.10 P.M.

SLAB E

Poured	Oct. 18	
Test Run 1	Oct. 26	4.30 - 8 P.M.
Test Run 2	Oct. 26	
Test Run 3	Oct. 26	
Test Run 4	Oct. 29	8 - 10.30 P.M.

APPARATUS

TESTING FRAME AND MISCELLANEOUS APPARATUS

In planning the tests it was early realized that some compromise would have to be made as to the size of the specimen. It had to be large enough so that the results would reflect the actual conditions, and at the same time as small as possible to keep the amount of effort required in making and handling these slabs to a minimum. Above all, it had to be small enough to be tested in some type of available testing machine or apparatus. The testing machines limited the size of the specimen to 2'-0" square which of course was too small. This meant that some type of apparatus had to be used. The Testing Lab had a testing frame large enough to permit the casting of a 5'-8" square slab. Due to the nature of the supports, this resulted in the slab being supported on a 5'-0" square. For a 6" thick slab this size was felt to be adequate.

The final setup as used for the slabs is shown in Plate 1.

The testing frame consisted of a head and four tie rods (two each side of the head). The two 12 I forming the head were fastened together by means of 6 x 6 angles welded to each beam. The tie rods, one 1 1/4 round and one 1 1/8 round each end, passed through holes in the beams.

The lower ends of the tie rods engaged in a continuous steel slot in the laboratory floor. The head was supported by two A-frames.

Unfortunately, as was later discovered, this frame proved inadequate both as to strength and rigidity. It was necessary to weld a 1/2" x 13" cover plate top and bottom to the two beams and to replace the two 1 1/8 round tie rods with 1 1/4 round rods. Side braces were added to increase the rigidity. Their tops were carefully fitted against the top flanges of the beams, while the bottom of each brace was fitted into a notched horizontal member. As a further precaution against rotation of the head, the bottom flanges of the beams were wedged into horizontal wood members. These wooden members were bolted to the side braces. The use of wedges under the braces and at the flanges provided a quick and simple method of leveling and tightening the apparatus. This revised arrangement proved satisfactory and gave complete reliability up to 150,000 lb. applied load.

The slab rested on four 8 I @ 18.4 lb. These were placed to form a square 5'-0" centre to centre of beams. The four corners of the square rested on four steel plates. These plates in turn sat on two 24 WF beams. The 24 WF were set at 5'-0" centre. Thus the centre line of the slab coincided in one direction with the centre line of the supporting square and the tie rods of the frame. In the other direction a vertical plane through the centre of the slab coincided with the centre line of the head, the centre line of the supporting square, and the centre line of the two 24 WF beams. This method of supporting the slab served two purposes. It supplied symmetrical bearing along the perimeter of the slab, and it permitted the edges of the slab to deflect in a manner similar to that of the column area in a flat slab floor.

The load was applied to the stub column of the slab with a 75 ton hydraulic jack which was bolted to the head of the frame. (See Plates 1 and 4.) The base of the jack rested against the two 12-inch I beams.

The recoil mechanism for returning the jack head into the jack consisted of a plate across the jack head. A 5/8 round rod was bolted through a hole in each end of the plate. These rods passed between the two 12 I beams of the frame head and a compression spring was placed over each rod. A nut and washer secured the springs in place. As the jack head moved out it compressed these springs. When the load was released the springs pulled the jack head back into the jack. Hydraulic pressure for the jack was supplied by a hand-operated hydraulic pump.

From the jack head downward to the stub column the following pieces of apparatus were placed in the order mentioned.

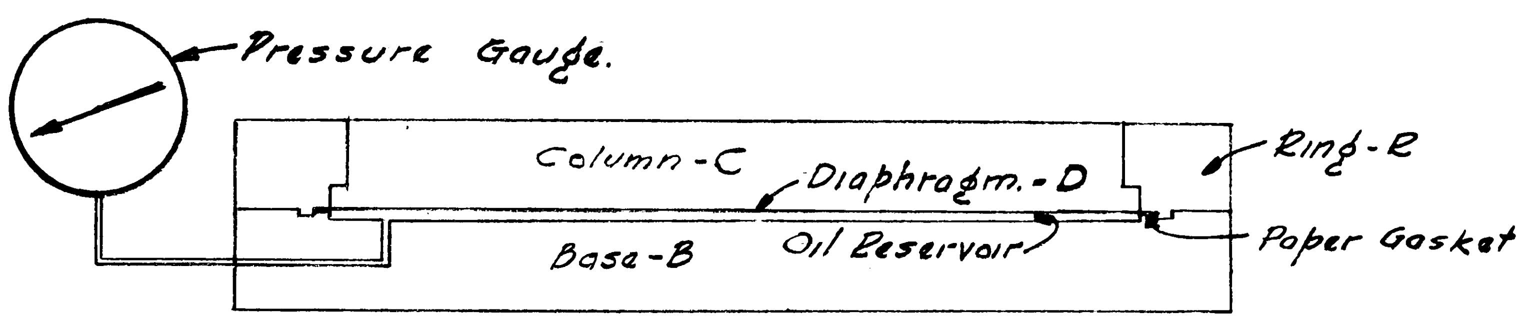
1. A one-inch thick filler plate
2. A ball and socket

3. The load-measuring device.
4. A steel plate, 2" thick and approximately 16" diameter.
5. A steel plate 18" x 1" x 1'-6".

These pieces of apparatus served several purposes. The ball and socket assured a point loading and also prevented the transmission of moment to the slab as a result of any rotation of the jack or frame head. At maximum total load (150,000 lb.) the unit load in the load-measuring device was about 14,000 p.s.i. Since the concrete is a considerably weaker material than steel and requires a much larger area to carry the load, the two large steel plates were used to distribute the load uniformly over the stub column. To assure complete bearing between the plate and the concrete column, it was necessary to cap the concrete with sulphur. The sulphur cap was carefully ground level and plane.

LOAD-MEASURING DEVICES

Capsule Originally the load-measuring device chosen for the experiment was an oil capsule similar to that used in the Emery Testing Machine. A cross section through the capsule is given below. (Figure 8) It consists of a heavy steel base (B) with a slight depression cut on its upper surface forming a reservoir. A thin brass diaphragm is placed over the reservoir and held in place with the clamping ring (R). A paper gasket is placed between the diaphragm and base to assure a perfect seal. The whole assembly is held together with bolts running through the base into the clamping ring. The column (C) is a thick steel plate sitting over the diaphragm. Both column and base have a series of concentric grooves. These are joined together by one radial groove which terminates in the outlet from the base. A 1/16" copper tube leads from the opening in the base to a Bourdon type pressure gauge. The reservoir, tube, and gauge are filled with a 50-50 mixture of glycerine and alcohol.



SECTION THROUGH OIL CAPSULE

FIGURE 8

The principle of the capsule is simple,--a load applied through the column C compresses the liquid to some pressure which may be read on the Bourdon Gauge. The product of the fixed area of the reservoir multiplied by the pressure is the value of the load. Due to the difficulty of completely filling the system, it was found simpler to place the capsule in the Emery Testing Machine and run a load test on it. In this way corresponding values of load and pressure gauge readings were obtained.

The calibration curves from tests made on different days give evidence that the capsule gave accurate results. The sensitivity of the device is fairly good and can be read accurately to about 350 lb. of applied load. The capsule was used on Slabs A and B, but since its operation was unreliable at loads over 100,000 lb. its use was abandoned in favour of another type of load-measuring device.

When used in the testing apparatus at loads over 100,000 lb. the capsule began to leak and so lost its calibration. On two occasions the thin diaphragm was torn. This meant the abandonment of that particular run of the test. The capsule then had to be refilled, recalibrated, and set back into the apparatus. About a month and a half was lost due to these delays and it was finally realized that a new type of load-measuring device would have to be employed. No difficulty was experienced with the capsule while calibrating it to 150,000 lb. in the testing machine. The trouble arose when it was used in the testing apparatus, which lacked the extreme rigidity of the testing machine. This was before the side braces were used, so that any rotation of the frame head produced an eccentric load on the capsule column. One of two things would occur. (a) The base would distort unevenly permitting the fluid to leak out, or (b) the thin diaphragm could not withstand the unequal loading and would tear. The writer has since (Nov. 1947) consulted Mr. Fred Murray of Truscon Steel Co. who used the diaphragm similarly several years ago. He stated that it failed at 70,000 lb. On the other hand, Mr. Jehu of the Dominion Bridge Co. used it successfully during April 1947 up to a load of 105,000 lb. In future the capsule should only be used where considerable rigidity of the testing apparatus will prevent eccentric loading of the capsule column and even then its reliability over 100,000 lb. is questionable.

The methods of replacing the gasket and diaphragm and of filling the capsule are given below.

<u>To Replace Gasket and Diaphragm</u>

1. Unscrew tubing and gauge from capsule.
2. Disassemble capsule by removing bolts.
3. Separate the component parts and wipe carefully with a soft cloth, making certain that no lint or small particles are left on the surface of the base and diaphragm.
4. Cut a paper gasket to fit. The paper used should be glue-sized. A sample is included in the back of the thesis. It should be bought as required. It is important that the paper be glue-sized since the sizing reacts with the glycerine, swells and forms a tight seal. The gasket should be replaced each time the capsule is opened.
5. Turn the base right side up and set it on two blocks so that the bottom of the base is about 3" from the top of the workbench. This permits the ring and column to be lowered onto the base and a few bolts put into place without disturbing the assembled capsule.

6. Set the paper gasket in place on the base. Place the diaphragm over the gasket being careful not to crease the paper gasket. If the diaphragm is new it will be a flat sheet of brass. The grooves are formed after the capsule has been used. Hence, on replacing the diaphragm, always load the capsule to its maximum (150,000 lb.) two or three times before running any calibration tests.
7. Screw the two lifting eyes into the column and suspend the column and ring from a chain block or pulley. Then lower the column and ring to about 1/16" from the base. There are two punch marks, one on the base and one on the ring. Rotate the ring until these two marks line up. Fasten the assembly loosely together with two or three bolts; then lower the column and ring onto the base. Next, tighten these bolts, turn over the capsule, and screw in the remaining bolts. The bolts should be tightened by alternately tightening those diametrically opposed.
8. It is important in assembling the diaphragm that no rotation of the component parts takes place as this might result in creasing the gasket with consequent leakage.
9. The diaphragm need not be replaced unless it is punctured or torn. Pin holes can easily be detected by holding the diaphragm up to the light.

To Fill the Capsule, Tube and Gauge

Capsule

1. Screw the lifting eyes into the column. Set the capsule on edge with the outlet opening at the top, and block to prevent the capsule from rolling.
2. Cork the outlet with a stopper containing a small funnel (see figure below) and fill the funnel with fluid (50-50 glycerine and alcohol).
3. Pass a piece of pipe through the lifting rings and wedge as shown with wooden wedges.
4. Drive the wedges tight with a hammer. This lifts the column, produces a partial vacuum in the capsule, and draws in the fluid.
5. When the level of the fluid has stopped dropping, remove the wedges and squeeze the capsule with two C-clamps, thus driving out the air.
6. Repeat 4 and 5 until no more air bubbles come out and the capsule can take no more fluid.

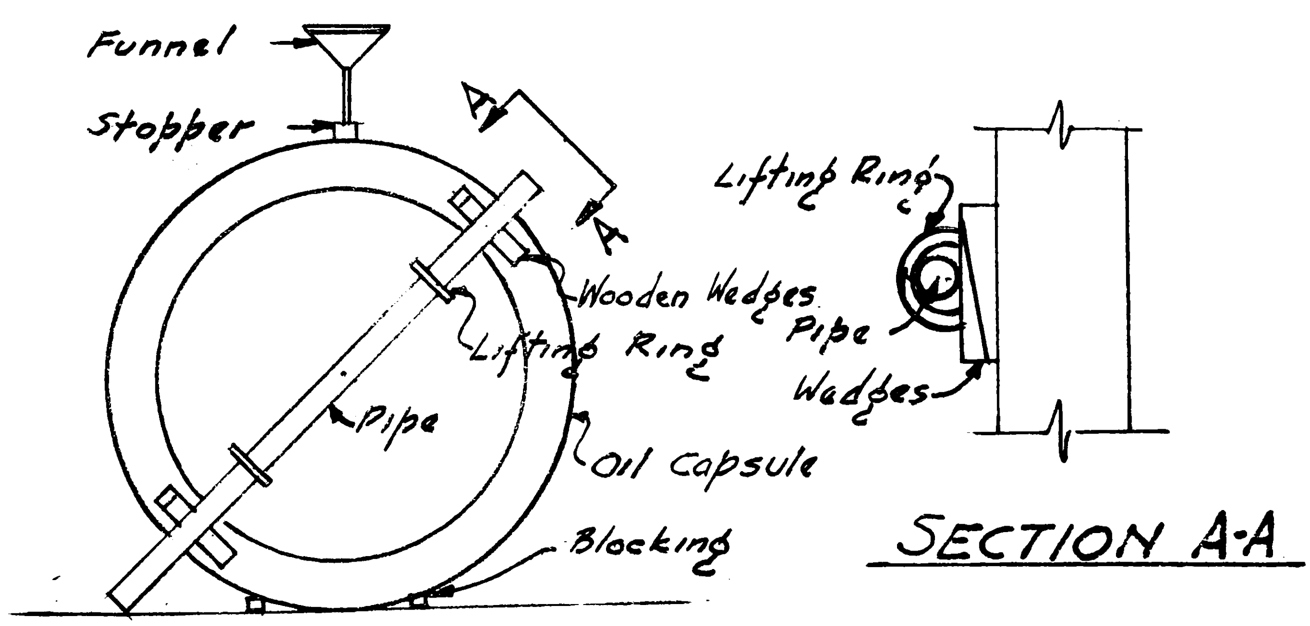


FIGURE 9

Tube

1. Pass a fine wire through the tube.
2. Fill the gauge coupling with fluid. Tap the tube gently, then withdraw the wire a few inches and repeat. The tube is filled when the fluid flows from the lower end in regular drops.
3. Screw the tube into the capsule and tighten in place with a wrench.
4. Keep the gauge coupling up in the air and repeat item 4 Capsule.

Gauge

1. Set the gauge on the workbench with outlet at top.
2. Pass a fine wire into the outlet as far as it can go (about 6").
3. Fill the gauge through the outlet with a pipette, withdrawing the wire slowly.
4. Repeat 2 and 3 until the gauge is full.
5. With the coupling held as high as the tube permits, screw the gauge into place and tighten with a wrench.

The capsule should next be tested. Three trial runs in close agreement will indicate whether the capsule is in working order.

LOAD BLOCK

Experience with the capsule had shown that the new load-measuring device, to be effective, had to fulfill the following requirements:

1. It had to be rugged enough to withstand any additional forces due to the lack of rigidity in the testing apparatus.
2. The sensitivity had to be no less than 1000 lb. of applied load.
3. The calibration had to be such that it would be unaffected by any slight error in positioning of the measuring device with respect to the jack head.
4. It had to retain its calibration in spite of handling during transit from the testing machine to the testing apparatus and during the actual test on the slab.
5. Its size had to be such that it could fit into the testing apparatus (maximum space available 11 1/2").
6. It had to be cheap and easy to construct.

The measuring block finally chosen consisted of a piece of railway car axle turned down to a cylinder 3.75" in diameter and 11.23" long, with four SR-4 Gauges mounted at mid-height and 90° apart.

The measuring action of this block is based on the principle that within the elastic range of the metal the same direct unit load will reproduce the same strain. By calibrating the device in an accurate testing machine, corresponding values of load and strain can be obtained. These strain values can then be used as a measure of the load in some other testing apparatus.

A unit stress of 15,000 p.s.i. in compression was set as the maximum for a total load of 150,000 lb. This low unit stress was chosen to allow for any increase in stress due to bending stresses set up by inaccurate positioning of the block, and to insure complete elasticity within the testing range.

A. S. T. M. requires that the height of a medium compression test piece be three times its diameter. Hence the block was made 11.23".

Some earlier work carried out by Mr. J. de Stein indicated the possibility of a slight inaccuracy in the SR-4 Gauge when used in compression. Professor Jamieson therefore suggested that the block be prestressed before mounting the gauges to eliminate this inaccuracy. The block was placed in the large Wicksteed machine and a compression load of 170,000 lb. applied at about 2.30 P.M. on July 10, 1947. With the load still at 170,000 lb. four gauges were then mounted with Glyptal Cement and air-dried until 3.15 P.M. To insure complete drying of the cement, a small wooden form was placed around the block, its open top stuffed with rags, and the interior heated with two electric lights. This gave a temperature of 150°F. around the block. The load and temperature were maintained until 7.15 P.M. when the heat was removed. The load however was maintained until 8.15 P.M. It was then removed slowly over a period of 20 minutes.

While two gauges mounted diametrically opposite were sufficient, four were used in case one was injured. This proved good insurance, because one gauge was damaged while wiring the load block. One pair of diametrically opposite gauges was wired in series. Two compensating gauges were used, also wired in series. (See diagram for final wiring setup.)

SR-4 Gauges are particularly suited for load measuring when used in this manner, since bending effects are eliminated and it is possible to obtain a calibration curve. Thus, one gauge measures direct compression strain plus tension strain due to bending and reads too low. The diametrically opposite gauge measures direct compression strain plus compression strain due to bending and reads too high. The effect of wiring the gauges in series is to add their separate values which automatically eliminates the bending strains. Thus any slight error due to positioning is eliminated.

The wiring and switching boxes were completed on July 16, 1947, and several calibration runs were made that afternoon. These proved to be disappointing since there was poor agreement between corresponding readings for the same load. It was felt that the adhesive was insufficiently dry and due to the prestress there was some flow resulting in the poor agreement of values.

On July 17 the block was placed in a drying oven and maintained at a temperature of 180°C. for three hours. It was then cooled in air and the gauges were given a coat of zophar wax, brushed on hot to protect the gauges against moisture.

On July 18 five calibration runs were made on the block (see Table 4). In Runs 1 and 2 the block was carefully centred in the testing machine. The block was moved off centre 1/8" for the third run, 1/4" for the fourth run, and 3/8" for the fifth. Corresponding values for the same load were in excellent agreement. Three runs were made on July 22 and these also indicated that the measuring block was reliable and accurate.

The block was sensitive to 310 lb. total load per micro-inch. The scale on the SR-4 recorder could be read or set accurately to ± 1 micro-inch, which gave the load block an accuracy of about 600 lb. total load. This was better than required.

There is one anomaly in the use of the block. Examination of the initial readings for July 18 and July 22 show that there is considerable variation between these values, but all the initial readings for each day are in very close agreement. Yet the increments of strain for all runs on both days are practically identical. Subsequent calibrations confirmed the above. This shift of the zero point is inherent in the recorder and not in the gauges or load block.

In using the block a calibration run was made just before testing the slab. If at the start of the test the recorder had shifted from the initial calibration zero, this difference was added or subtracted to the calibration values depending on whether the shift was positive or negative. These new values were used in testing the slab. Since each test run lasted a maximum of three hours, this procedure was found to give reliable results with almost no shift between the initial zero at the start and completion of a test run. Immediately after the fourth run on each slab, a new calibration run was made on the block to make certain that there had been no great variation in the strain increments.

The SR-4 Gauges are electrical resisters. Any change in the resistance of the external circuit will affect the strain readings and produce inaccuracies which are impossible to evaluate. For this reason there must be no disturbance of the electrical setup once the calibration run has been made. This policy was strictly adhered to throughout the tests. Once the block was calibrated it was never disconnected from the recorder until the slab test was completed. A broken connection meant recalibration.

SR-4 STRAIN GAUGES

SR-4 Strain Gauges are the most recent addition to the testing and research engineer's tools. Essentially, they consist of a five-inch length of 1 mil copper-nickel wire bent in the shape of a grid, and fastened to a piece of cigarette paper. A piece of red flannel glued to the grid protects it from damage in handling. In use, the gauge is cemented to the test specimen with some type of plastic cement.

Any variation in length of the specimen varies the length of the wire and hence changes its electrical resistance. Since the resistance of a piece of wire varies directly as its length and inversely as its cross-section, it becomes possible to use this change in resistance as a measure of the strain in the specimen. The resistance change can be measured by some type of Wheatstone bridge. The usual type of measuring instrument is the SR-4 Strain Recorder. It consists of a Wheatstone Bridge with an electronic amplifier. The slide wire forming one arm of the bridge is calibrated to read directly in micro-inches of strain. Standard resistances form the second arm. The active gauge forms the third arm. The fourth arm consists of a gauge, preferably from the same gauge lot, mounted on a piece of unstressed material of the same kind and subject to the same temperature conditions as the member to which the active gauge is attached. It automatically cancels out any strain effects due to temperature. This instrument is fast and accurate, with the exception of the zero shift (see above). Complete information on the construction and use of both the SR-4 Gauge and Recorder may be obtained from the manufacturer.

Three types of SR-4 Gauges were used in the tests. Type A-1, which is more or less the standard gauge, was used on all main reinforcing steel and on the four steel beams. It has a resistance of approximately 120 ohms with a gauge length of 13/16". This type can be mounted on 3/8 round bars and larger, hence special gauges were required for the 1/4 round shear reinforcing bars. Baldwin Southwark recommended and supplied Type A-1-4 for this purpose. This type is the same as A-1 except that the paper is much thinner, hence more flexible. These specials did not arrive in time for Slab B and ten Type A-12-4 were obtained from the Department of Mines in Ottawa. This gauge has a resistance of approximately 120 ohms with a gauge length of one inch. Actually, this gauge was more suitable for the 1/4 round bar than Type A-1-4 since its gauge width is 1/8" as opposed to 11/32" for Type A-1-4.

The SR-4 Gauges used in these tests were mounted on the steel reinforcing bars and embedded in concrete. The adaption and protection of the gauges for this use proved to be a considerable problem, which was finally solved successfully. The methods used are described below in detail.

Earlier work in the lab showed that the problem was one of waterproofing the gauge. Poor waterproofing resulted in rusting under the surface of the gauge. This first grounded the gauge to the bar and then gradually lifted the gauge off the bar.

Preliminary work consisted of trying several
ypes of waterproof adhesives which were applied over the
auges as a protective coating. The use of these coatings
as unsuccessful since (a) they failed to form a waterproof
ond with the steel, and (b) any slight movement of the lead
ires would crack the covering. The point at which the lead
ires leave the protective covering is the most vulnerable
pot. To reduce the chance of leakage at this point, one of
he wires was grounded to the bar within the area covered by
he waterproofing. This practice was carried out on the
auges for Slab B but was abandoned for the remaining slabs.
t was necessary to use considerable heat when soldering the
auge lead wire to the reinforcing bar. Unless extreme care
as taken, the heat from the soldering iron would injure the
auge.

The method of waterproofing used in Slab B was
uccessful. It has some advantages over the method used in
labs C, D, and E. However, it requires more time and un-
ess extreme care is exercised it is not as positive a pro-
ection as the latter method. For these reasons it was dis-
arded in favour of Method 2 which will be described later.

ethod of Mounting and Waterproofing Gauges

s Used in Slab B.

reparation of Bar

1. The approximate position of the gauge was chalked on the bar. This area was then cleaned with a file and the surface of the bar left slightly rough. The exact position of the gauge was located by scribing two lines at right angles on the bar. Any loose rust or scale around the filed area was then removed with a scratch wheel chucked in an electric drill.
2. A drop of solder was placed on the bar close to one end of the gauge. This helped to reduce the danger of damaging the gauge when the lead was soldered to the bar.

lounting

Mounting the gauge on a round bar was handled in :he following manner. For both 5/8 round and 1/4 round bars ɪ small concave wooden block was used. The diameter of the ;urved surface was 1/16" greater than the rod. A rectangle ɔf cardboard 1/32" thick was glued against the concave wood surface. An opening slightly larger than the felt pad was then cut in the cardboard. The size of the block was made about 1/8" larger all around than the felt pad.

The cement used to fasten the gauge to the bar was "Glyptal". Before mounting, the surface of the bar was wiped with acetone to remove any grease or perspiration. The surface of the bar and the underside of the gauge were then covered with a thin coating of cement. As soon as the cement had become tacky the gauge was placed on the bar, then the wood block placed over the gauge. The gauge was positioned by lining up the gauge centre lines with the two scribed lines. A piece of electrical tape was then wrapped around the bar and the block.

<u>Drying</u>

It is essential that the cement be thoroughly dry. The gauges were first air-dried for half to one hour, then placed in a drying box and kept at a temperature of approximately 160°F. to 180°F. for three hours. Air-drying reduces the formation of small air bubbles in the cement. The homemade drying oven consisted of a wooden box 12" wide, 6" high, and 6'-0" long. Six 100-watt lamps were placed on the bottom on asbestos sheets. The lamps were covered with pieces of metal stovepipe to distribute the heat uniformly. The bars were set on wooden stands. The cover was then set in place with a thermometer corked in the centre. The six lamps maintained the required temperature.

<u>Attaching the Conductors</u>

After removing the bars from the oven, the wood blocks were removed and any excess cement scraped off. One lead was then soldered to the bar. The other lead was soldered to a wire conductor. No. 18 Flameseal solid core wire was used for all slabs. This is a plastic-covered wire completely waterproof and impervious to the chemical action of the cement. A solid core wire is essential. Stranded wire should never be used. If one of the strands should break, the electrical resistance of the circuit would change and the gauge readings become erratic and useless.

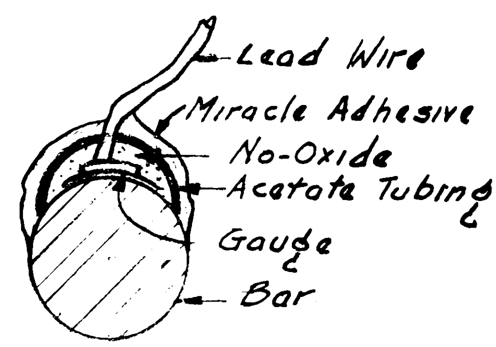
It was found that the connection was most quickly accomplished by first flattening the end of the conductor in a vise, then drilling a hole in the flattened end with a No. 60 drill. The fine lead wire was threaded through the hole and twisted around the conductor. The lead wire was then soldered to the conductor with a good grade of rosin core solder. Acid paste or acid core solder should never be used as it will eventually corrode the leads. The conductors were then taped to the bar at two points. This takes the strain off the lead wires and prevents them from being torn from the gauge.

Testing

Before waterproofing the gauges, each was tested to ascertain whether any had been injured in mounting or handling. Testing was best carried out with a sensitive Wheatstone bridge. If the resistance of the gauge measured within $\pm$ 0.3 ohms of the value given by the manufacturer, it was passed. This was considered to be sufficiently close since alligator clamps were used and their contact resistance could produce this variation. In one case there was some doubt as to whether the gauge had been properly cemented to the bar. The gauge was tested by cantilevering the bar with the gauge uppermost and with its centre over the support. Known bending moments were applied by hanging weights from the bar at a distance of ten inches from the support. The strains were computed and these were checked against the measured values. The gauge proved to be working correctly.

Waterproofing

A piece of 1/2" O.D. acetate tube was split lengthwise. A 2 1/2" length was used for each gauge. Two holes were drilled in the top of the tube, one in the centre, and one about 1/2" from one end. The wire conductor was passed through the centre hole. The split tube was clamped against the bar. Then the tube and the bar for a distance of 1/4" from the edge of the tube were smeared liberally with "Miracle Adhesive". This was thoroughly dried in the drying box. On removal, hot "No-Oxide" was poured through the second hole in the tube, filling the space under the tube. "No-Oxide" is a grease-type rust preventative. A second coat of "Miracle Adhesive" was then smeared over the first, particular attention being paid to the area around the conductor. The bar was then put back into the drying box. This served two purposes. (a) It dried the adhesive and (b) melted the "No-Oxide" so that it flowed over the gauge and filled any pockets formed in the



SECTION THROUGH GAUGE & BAR

FIGURE 10

initial pour. This completed the water-proofing procedure. (Method A)

Method B

Shortly after Slab B had been poured, information was received from the Department of Highways, State of Illinois, on a technique which they had developed for using SR-4 Gauges in concrete. The technique was simple, and test data which they were kind enough to supply indicated that the method was reliable. It was therefore decided to obtain the materials which they had used and to try the method on Slab C. The waterproofing material was an asphalt compound, Petrolastic No. 155, and two gallons were supplied free of charge by the Standard Oil Co. of California. The technique used is described below.

The gauges were mounted on the bars as previously described. The reinforcing bar was set on two blocks so that it could be rotated. The side of the bar opposite the gauge was heated with an infra red ray lamp for about five minutes. A thin coat of hot Petrolastic was next applied with a steel brush completely around the bar, over the gauge, and for a length of three inches. The heat lamp was then directed against the Petrolastic and the bar rotated. When the material began to run, it was thoroughly brushed with the steel brush to assure good bond between the steel and the Petrolastic. The heat was then removed and the conductors soldered to the gauge leads. To prevent any pull on the conductors being transmitted to the lead wires, the conductors were doubled back over the top of the gauge. To insure complete electrical insulation, the conductors were kept 1/8" apart. The Petrolastic was again reheated and more brushed on until the leads were completely covered and the layer of waterproofing built up to 1/8" thickness. To prevent any leakage around the conductors, they were predipped in hot Petrolastic, coating them for a length of six inches.

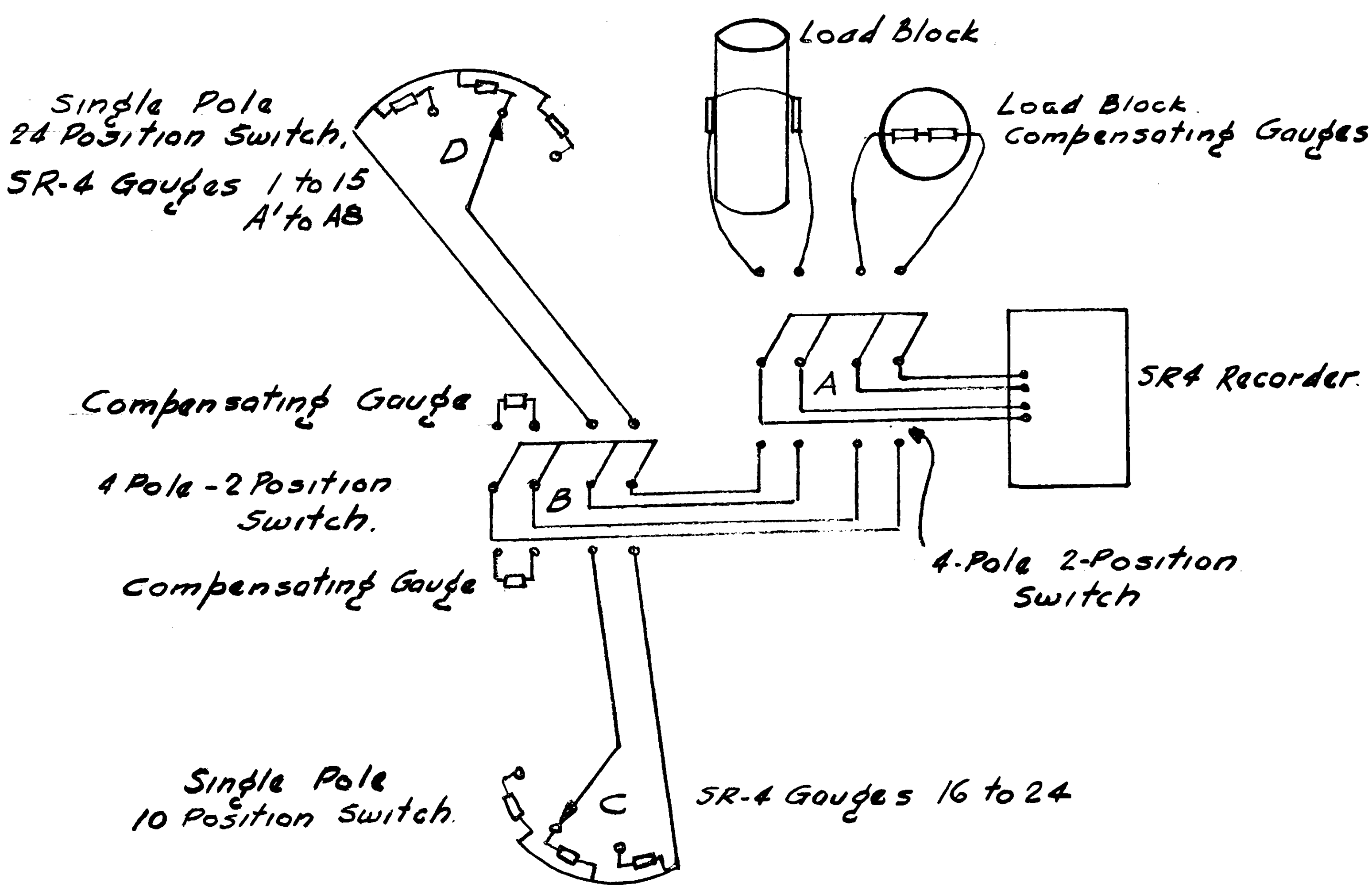
Both methods of waterproofing are compromise solutions. Method A has the advantage of destroying less bond area, hence disturbs the stress distribution less around the gauge. The time required to mount and waterproof a gauge varies from 1 1/2 to 2 hours. Where 24 gauges are to be used in one test, this represents almost a week's work. Method B is considerably faster and more reliable, but completely interrupts the bond for a length of three inches. For laboratory specimens which must of necessity be small, this may represent a considerable reduction in available bond area. Some method of waterproofing is required which will overcome the above difficulties.

Switching and Wiring

The large number of gauges used per test required that some type of switching arrangement be used with the one recorder. It had to serve the following functions:

(a) Connect in the load block with its compensating gauges.

(b) Connect in the 15 gauges on the tensile reinforcing, the 8 shear reinforcing gauges, and the 8 gauges on the steel supporting beams. The gauges in Group B further complicated matters by requiring two separate compensating gauges. With the help of Mr. Tom Pavlasek of the Electrical Department, a switching arrangement was obtained (see figure below) which fulfilled all requirements. The proper choice of switches assured that the compensating gauges were automatically switched into the circuit with their corresponding gauges.



WIRING DIAGRAM - SR-4 GAUGES

FIGURE 11

Both toggle and wafer type switches were used. It was important that the contact resistance for any one position of the switch did not change with each reading. The switches were checked by balancing the recorder and then turning the switch on and off several times. If the recorder returned to its initial balance, the switch was considered satisfactory. Small variations of a few micro-inches were ignored.

Switch A selected the load block or test gauges. Switch B selected the groups of Gauges 1 to 15 and A-1 to A-8 or 16 to 24 as desired. The first group required one compensating gauge while the second group used another. Switches C and D selected the individual gauges.

For the sake of economy and ease of handling, the conductors soldered to the gauge leads were only 30" long. It was therefore necessary to lengthen these leads after the slab was set in place. No. 14 solid core copper wire was used for this purpose only because a large quantity of this size was discarded by some electricians working in the building. Normally, the same size as the conductors would have been used. All joints were carefully soldered. Considerable time was saved in setting up by connecting one side of the gauge to a common ground.

HUGGENBERGER TENSOMETERS (See Plates 1 and 2)

Strain measurements on the concrete were made with six Huggenbergers. These are very accurate extensometers consisting of two knife-edge supports and a lever system. One support is fixed, the other rotates. The amount of rotation is a measure of the strain in the specimen. These instruments operate like the Martens Extensometer, except that the mirror and scale have been replaced by a compact and accurate multiplying lever system.

These instruments can be mounted very quickly in almost any position. The method of mounting the gauges for these tests is clearly shown in Plate 2. The mounting supports were angle brackets cemented to the slab. A mounting bar was slipped through a hole in the gauge and in the angle bracket. To assure good bearing for the knife edges, two small round brass pads were cemented to the slab. These were set so that their upper surfaces were in the same plane. The gauges were mounted along one diameter and along one diagonal directly over an SR-4 Gauge. (See Figure 5 for location.)

<u>DEFLECTION SCALES</u> (See Plate 3)

As an overall check on the action of the slab, nine deflection gauges were used on the underside of the slab. Four were placed along a diagonal, four along one diameter, and one at the centre of the slab. The lab floor served as the base line and support for the fixed end. The applied load to the slab was resisted by the apparatus and hence did not affect the lab floor. The deflection gauge was made from a ten-cent telescoping curtain rod.

The gauge was held in position against the slab in the following manner. Two centre lines were scribed on a small rectangle of sheet metal. A roofing nail passed through the sheet metal at the point of intersection. The shank of the nail engaged in a hole in the rod, holding the rod firmly in place. The sheet metal rectangle was cemented to the underside of the slab, using the two scribed lines for centering. The halves of the curtain rod were attached to a coiled spring which pushed them apart and held the upper half tightly against the bottom of the slab. A 3-inch length of steel scale graduated in fiftieths and hundredths of an inch was used on each deflection gauge. The gauges were read through telescopes set about 5'-0" away.

The gauge positions were marked on the oiled slab form with a lead pencil. This acted like a transfer, and when the slab was lifted out of the form these pencil lines were found on the slab surface. It was easy and accurate to lay out these lines on the forms, whereas locating the gauges after the slab was positioned would have been difficult and not as accurate.

FORMS, MATERIALS, AND TESTING PROCEDURE

FORMS

The slabs were cast in the lab in a wooden form. Since they were to be tested with the column uppermost, they were cast in this position.

The form consisted of a wood deck supported on five 2 x 4 stringers spaced at 17 1/2" on centres. These in turn were carried on three 2 x 4 beams placed at right angles to distribute the load to the floor. The sides of the form were built of two form boards cleated together. For details of the corner and sides see Plate 7. This method of constructing the sides permitted the forms to be assembled and stripped with a minimum of effort and with no destruction of the forms. The slab deck was covered with B. C. Fir plywood to give the slab a smooth finish.

The column form consisted of a box, open top and bottom, and supported by two 2 x 4. These were in turn supported from the main form, and blocked to prevent the column form from shifting. The column panels were held together with kicker-strips to facilitate assembling and stripping. Chamfer pieces 1 1/2 x 1 1/2 were set in each corner.

As soon as the slab had been removed, the form was cleaned, assembled, and oiled with old crankcase oil to preserve the wood and to facilitate stripping. The outside of the form was also oiled. This prevented any concrete spilled over the form from sticking.

MATERIALS

Materials used in making the slabs were procured locally. These were similar to materials used by contractors in the city for the making of reinforced concrete.

Sand

Charrette sand was used since it has good grading, as may be seen from the sieve analysis (see Table 5). The sand ordered for the tests only lasted for Slabs A, B, and C. Sand for Slab D was taken from the laboratory stockpile, while that for Slab E was bought locally. Nevertheless, all the sand used was Charrette. The sand was thoroughly air-dried by spreading it on the lab floor.

Stone

Crushed limestone, known locally as 3/4", was used on all slabs. Sufficient was ordered for all tests. The sieve analysis (see Table 5) indicated a fineness modules of 7.54 and the grading about 56% retained on the 3/4" sieve and 43% on the 3/8" sieve. All stone was thoroughly air-dried by spreading it on the lab floor.

Cement

To shorten the time between pouring and testing of the slabs, High Early Strength Cement was used. Enough cement was ordered for casting all the slabs. Due to the delay caused by the failure of the apparatus, this cement was used only for Slabs A and B. Actually, it had begun to lose its high early strength properties by the time it was used for Slab B. This accounts for the lower strength of concrete in this slab. The High Early Strength Cement for Slabs C, D, and E was obtained from the Canada Cement Co., direct from their plant at Montreal. A day or two before pouring, the cement was picked up at the warehouse. This assured fresh cement for each slab.

Steel

The reinforcing steel was bought from Truscon Steel Co. Ltd. The 5/8 round bars were ordered bent to shape. The 1/4 round bars came in twenty-foot lengths. The shear bars for Slabs B and D were bent in the lab on a small hand bender built for these tests. The coils used in Slab C were coiled locally at a machine shop on a spring coiling lathe.

CONCRETE AND CASTING OF SLABS

Every effort was made to obtain uniform concrete. The cylinder tests for any one slab indicate close agreement and show that this was accomplished. Preliminary mixes indicated that the following proportions by weight would give a mixture having good workability (slump about 4"), would not be too wet, and would test at about 3000 p.s.i. ultimate at seven days.

<u>Quantities Per Batch</u>

Cement 34 lb.

Sand 112 lb.

Stone 138 lb.

Water 23 lb. 14 oz.

The cement had lost some of its high early strength properties by the time these preliminary mixes were made. The cement later obtained gave the mix the same advantages but the strength of the concrete was higher. Concrete, even with good control, has many variables and indeterminacies so that changing the mix for Slabs D and E would only have made the problem more complicated. Besides, the delay of one month between Test Run 3 and 4 on Slab B gave the concrete added time in which to increase in strength. In view of this fact, comparison of the ultimate breaking load for Slab B should be based on an ultimate concrete strength comparable to that of Slabs C, D, and E.

The concrete was mixed in a small gasoline-driven mixer (see Plate 1). The sand and stone were weighed into closely woven jute bags. The cement was weighed into heavy waxed paper bags. All materials for any one slab were weighed out beforehand and placed conveniently near the mixer. Thus there was no delay once concreting had begun.

The mixer was loaded in the following manner. First the water was poured into the mixer. Next the cement was added, then the stone, and finally the sand. If the sand was added before the stone, it tended to clog in the blades and the proportions per batch showed variance. The stone, when added first, produced a scouring action which prevented clogging and resulted in a uniform mixture. The materials were mixed for a minimum of three minutes after everything had been added. The concrete was dumped into a wheelbarrow and conveyed to the form. The mixer supplied two barrows per batch and was completely emptied before reloading. To prevent any damage to the gauges, the concrete was shoveled into the form. As soon as the concrete was placed, it was thoroughly rodded with a 5/8 round bar.

After the form had been filled, the top of the slab was struck off level with a wooden straightedge. About two hours later when the surfaces of the slab and column had set somewhat, they were rubbed with a wooden float and then polished with a steel trowel.

Test cylinders were filled at equal batch intervals as concreting proceeded. Since the consistency varied slightly between the first and second wheelbarrow in any batch (typical of all concreting), sampling was carried out in a definite way. Cylinders were alternately filled from the first and second wheelbarrows. All test specimens were cast in standard 6" x 12" cylinders and filled in accordance with A. C. I. specifications. (See A. C. I. Manual of Concrete Inspection, pp. 87 - 88.)

Curing

The day after pouring the slab, column and test cylinders were stripped. The slab and column were covered with wet jute bags. Each test cylinder was covered with a wet bag and set on top of the slab. The whole was covered with a tarpaulin. The bags were wet down each day. On the fourth day the bags were removed and the slab set in place on the 8 I beams. Before setting the slab, the top flanges of the beams were covered with grout. When the slab was set in place it squeezed out the excess grout, thus assuring complete bearing everywhere between the slab and the beams. The excess grout was cut off with a trowel.

The test cylinders were capped with sulphur. Capping was done in a jig. This assured that the two ends against which the load was applied were plane and parallel, and that the load was applied along the axis of the cylinder. Compression tests on the cylinders were carried out in the testing machines. The cylinders were cured under exactly the same conditions as the slab. See Table 6 for test results on the cylinders.

TESTING PROCEDURE

Purpose The testing procedure chosen had three aims:

1. To indicate the behaviour of the slab under load.
2. To indicate the action of the shear reinforcing under load.

3. To obtain some idea of the effectiveness of the shear reinforcing by comparing the ultimate breaking loads of the four slabs.

The C. E. S. A. code requires that a building under test, "shall be subjected to a superimposed load equal to one and one-half times the live load. This load shall be left in position for a period of 24 hours before removal." When first planning the test procedure, it was assumed that the slab could be designed for a working load equivalent to 0.06f'c on the critical section. On this basis, with 3000 lb. concrete the slab would carry a safe working load of 61,300 lb. If half of this load were live load and half dead load, the test load would be $\left(\frac{61300}{2} + \frac{61300}{2} \times 1.5\right)$ = 76,500 lb. Allowing for the increase in concrete strength (3270 p.s.i.), Slab B was tested to 80,000 lb. Slabs C and D were tested to 90,000 lb. because of the further increase in concrete strength. Since Slab E had no shear reinforcing, the test load was reduced to 70,000 lb.

Procedure

1. Several test cylinders were broken just before the test.
2. A calibration run was made on the load-measuring device and it was then put in place in the apparatus.
3. Load was then applied to the slab in increments of 10,000 lb. Readings of all gauges were made at each increment. The gauges were always read in the same order.

4. When the load had reached a predetermined value, (80,000 lb. for Slab B; 90,000 lb. for Slabs C and D; 70,000 lb. for Slab E) it was removed.
5. Steps 3 and 4 were repeated twice.
6. The slab was then reloaded to the values given in Step 4 and blocked in place with two 3-inch H sections. These H sections were symmetrically placed between the underside of the head beams and the top of the round block of steel. The jack was then released. Approximately 10,000 lb. reduction in load took place when the jack was released. After conditions had become steady, the gauges were read. The slab was left blocked for two days. Before removing the blocking the gauges were again read. Then the jack load was reapplied and the blocking removed. The load was released and the final run carried out.
7. In the last run the slab was loaded with 10,000 lb. increments until it broke. Readings on practically all gauges were taken up to the time of failure.
8. The load-measuring device was recalibrated.
9. For Slabs D and E sufficient test cylinders had been cast to permit testing two of them immediately after calibrating the block.

EXPERIMENTAL DATA AND DISCUSSION

BEHAVIOUR OF APPARATUS

The apparatus in its final form (see Plate 1) gave excellent service without any breakdown either in the testing frame or in the load-measuring device. It was used on the last test run for Slab B and on all runs for Slabs C, D, and E. Its maximum capacity is 150,000 lb. The only suggestion the writer has to make on the load-measuring device is that it should in future be made from high grade steel, and spool shaped to increase the sensitivity. (See figure below.) A separate recorder for the load-measuring device when used in conjunction with the other SR-4 Gauges would be advantageous.

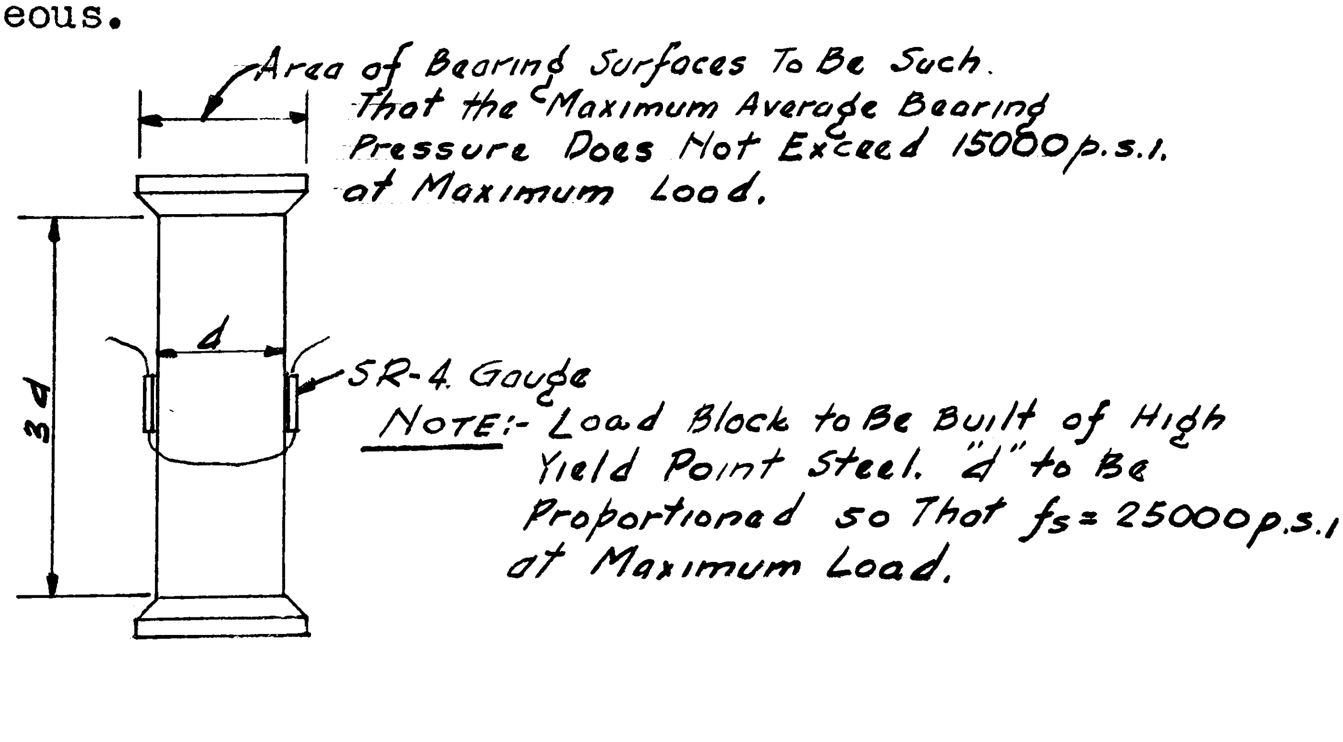


FIGURE 13

The SR-4 Gauges gave excellent service throughout the experiment. Of the 87 gauges mounted and used in concrete, only six (6.9%) failed to operate adequately. The rest performed accurately as shown by the fact that corresponding gauges showed readings which were of the same order.

The deflection gauges, being of rugged construction, operated very well.

The Huggenberger Gauges showed the largest percentage of inoperation. Experience gained from this experiment indicates that the surfaces of the mounting pads must be in the same plane. Failure of Gauge 1846 to operate properly was due to a slight inclination of one pad with respect to the other. This permitted the knife edges to slip.

In examining the data, it is important that the following facts be borne in mind:

(a) Concrete is not a completely elastic material, but rather an extremely rigid plastic which is subject to progressive and cumulative deformation under load. The material takes on permanent set and is affected by the rate of loading so that corresponding deformations for the same repeated load are not identical. This affects not only the concrete strains but also the steel strains and, to a much lesser extent, the deflections.

(b) While each slab was reinforced in exactly the same manner with respect to the tensile reinforcing, the shear reinforcing varied in type, spacing, and quantity. This affected the bending stresses somewhat, so that corresponding gauge positions do not give the same readings for corresponding loads.

(c) Although every possible precaution was taken to insure proper centering of so large a specimen in the apparatus, small variations did take place. This, accompanied by the fact that a testing apparatus and not a testing machine was used, helped to introduce variations in the readings. Further variations were brought into the readings by slight inaccuracies in placing the load-measuring device and in setting load values on the recorder.

PRESENTATION OF DATA

The results for all strain and deflection readings are presented in tabular form. The strain readings on the tensile steel and the concrete, and deflection readings for each run of each slab have been grouped together (see pp. D 1 to D 16). This facilitates comparison of the readings for corresponding conditions of loading and for repetition of loading between slabs as well as for each slab. The strain readings on the shear reinforcing are grouped together for each slab (see pp. D 17 to D 21). The completely different types of shear reinforcing in Slabs B, C, and D, make meaningless the comparison of corresponding gauge positions between slabs. The readings showing the effect on the slab of long-time loading are given in Table 8.

The values at the top of each column represent the difference between the initial readings of the first run and the initial readings of the three succeeding runs.

Discussion of the data is made under the following headings:

(a) Shear Reinforcing

(b) Bending Effects

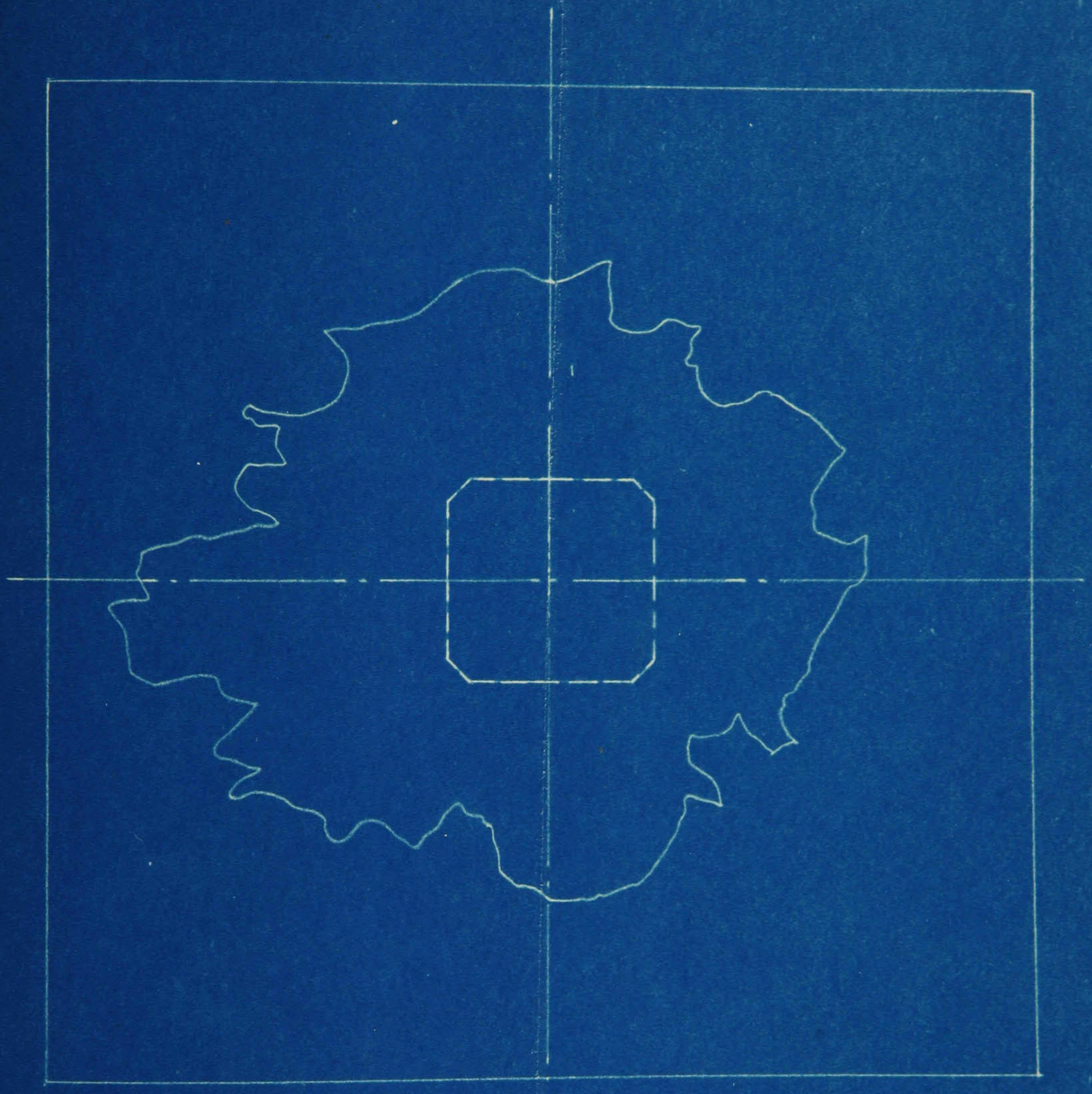
(c) Behaviour of the Slab under Load

SHEAR REINFORCING

All the slabs failed in diagonal tension at about the same ultimate load (see Table 6). It was impossible to observe the formation of shear cracks, but the type and inclination of the failure were definitely due to diagonal tension. When the slabs were broken up, care was taken to disturb the original plane of failure as little as possible. In all cases the slope was less than the usual 45° to the horizontal and more like 30°. In every case the column, with this added mushroom head, separated from the slab and pushed down the grillage of steel. There was some sound of cracking before the crack appeared on the compression face of the slab, indicating that failure started at the tension steel and progressed into the compression area, as is the usual case for beams. In all cases the plane of failure passed through some of the shear reinforcing. The failure crack more or less extended around the periphery of the column in Slabs C, D, and E. With Slab B the failure crack moved outward away from the column on two sides, as may be seen in Plate 17. Only in Slab C did the mushroom part project sufficiently at failure to indicate this failure area on the underside of the slab. The crack was carefully plotted to scale and is shown in Figure 12.

The gauges mounted on the shear reinforcing show that this steel carried very little stress even at the upper loads. The maximum unit strain recorded was 617 micro-inches for Gauge 18, Slab B. However, this gauge was erratic from the first and its values are not considered reliable. Gauge 20, Slab C, showed a maximum strain of 492 micro-inches. This corresponds to a unit stress of 14,760 p.s.i. The remaining gauges indicate a maximum stress of about 6000 p.s.i. and this value only in a few cases near ultimate load. On the whole, the unit stresses in the gauges were considerably less.

The compression strains in the coils of Slab C were probably due to the direction of coiling. These coils were wound counterclockwise. The curvature of the slab under load was clockwise. This tended to unwind the coils and put the steel in the vicinity of the gauges in compression.



SHAPE & LOCATION OF SHEAR FAILURE ON TENSION SIDE - SLAB C.

1" = 1'-0"

FIGURE 12

BENDING EFFECTS

As stated previously, the gauges on the tensile steel were placed so as to give the variation of bending moment along the slab rather than across it. These positions were best for indicating the change in bending moment as a measure of shear, but were not as valuable for suggesting the variation of bending moment across the slab. The designer is chiefly interested in the latter. Still, the gauge readings have considerable value. Examination of the strains indicates that the gauges around the column show the greatest strain, and correspondingly, the greatest stress. The bars in this area did not reach their working stress until the applied load was 60,000 lb. At 70,000 lb. Gauges 3, 6, and 7 show considerable overstress, but not above the yield point; Gauges 12 and 13 are still at about 20,000 p.s.i. The next group of gauges, Nos. 5, 2, 11, 14, and 8 show no overstress at 70,000 lb. although the steel is very close to the allowable working stress of 20,000 p.s.i.

The concrete close to the column shows stresses which are high at 50,000 lb. applied load. Assuming Ec to be 1000 f'c and the allowable working stress to be 0.40f'c, Gauge 1847 shows the concrete to be overstressed in 50% of the runs at 50,000 lb. total load. At 60,000 lb. the overstress occurs in 75% of the runs. Gauge 1846 does not show such high stress. However, its position was slightly further away from the column than 1847. The other four gauges show very low stresses of about 300 p.s.i. or 400 p.s.i. There and 12 are also much higher than those calculated. These positions are around the column. Gauge 13 shows values about the same as those calculated. In the next group of gauges,--5, 2, 11, 14, and 8, the calculated values are in closer agreement with the observed values, but even among these, Gauges 5, 8, and 2, show slightly higher strains than those calculated. At the lower loads the observed and calculated values of Gauge 11 are about the same, but at the upper loads the observed values exceed the calculated values. For gauge position 14, the observed and calculated values are about the same. This comparison indicates the unevenness of the stress distribution when the column cap is removed.

BEHAVIOUR OF SLAB UNDER LOAD

As stated previously, the test procedure attempted to show how the slabs acted under both short and long time loading. Up to about 60,000 lb. nothing visible occurred. Each slab seemed to operate consistently and without sign of any local effects. Between 50,000 lb. and 60,000 lb. of load, tension cracks paralleling the column outline were first evident. Usually some tension cracks radiating along the diagonal started to form near the column at about the same time. The fan of cracks spread toward the diameters of the slab with increasing load. At about 90,000 lb. some cracks showed along the edges of the slab near the corners. These were inclined at 45° to the horizontal. At 70,000 lb.

there was visible lifting of the corners of the slab. This curling continued to increase and near failure was quite substantial. Generally, the behaviour of the slab predicted the failure about 10,000 lb. before its occurrence. There was some noise indicating internal cracking, although the load could still be maintained to some extent and the gauges could be read. On attempting to increase the load, the slab would carry the increase for a few moments and then start to throw off the load. As the pumping continued, its ability to carry the load decreased until a complete fracture resulted and failure took place. In Slabs B, D, and E, failure was not violent. With Slab C the failure was rapid and violent, shaking the apparatus considerably.

Plates 11 to 14 show the cracks on the underside of the four slabs. They are all fairly similar, indicating further that the shear reinforcing had little or no effect. Plates 15 to 17 are closeups of the shear failures which were visible from the top of the slab. The slope of the failure is suggested in these photographs. The slab recovery in percent of the maximum total deflection for each run is given in Table 9. In all cases the recovery is over 75% of the total deflection. The recoveries bear out the stresses shown by the SR-4 Gauges and Huggenbergers, indicating that at about 70,000 lb. of load both the concrete and steel were still within the elastic range. The recovery after two days of continued high load was good.

Table 8 contains the gauge readings taken (a) just after blocking the slab, and (b) just before removing the blocking. Its purpose was to see if there had been any redistribution of stress as a result of the long time load. Since the slab had been blocked in place, the deflections did not change. The SR-4 Gauges changed very little in both directions. Gauges 12, 13, and 14, in Slab D, showed large movements in the same direction. These are incompatible with their behaviour in Slabs C and E and cannot be explained. On the whole, there seems to have been little change in strain in the steel. The Huggenberger Gauges do seem to indicate some redistribution of strain in the concrete. Gauge 1847, which showed the greatest strain in all runs, dropped consistently in Slabs C and D but did not move in Slab E. A similar anomaly occurred with Gauge 1846. The remaining gauges do show a release of strain.

CONCLUSIONS

On the basis of the data previously presented, the following conclusions, falling into four main groups, appear warranted.

SHEAR REINFORCING

The ultimate failure load of the unreinforced slab and reinforced slabs being approximately the same, it is evident that the shear reinforcing used in these tests is ineffective and produces no increase in the strength of the slab. The results of beam tests made by Mr. B. A. Eskenazie indicate that neither are stirrups effective as shear reinforcing in shallow beams. The gauges mounted on the shear reinforcing show little strain in this steel. It seems quite definite that if the slab is to be effectively reinforced against shear some method must be devised which will develop the value of the reinforcing through bond.

The results suggest that a revision is needed in existing codes limiting the use of stirrups to deeper beams.

The results show that the code can be extended to include flat slab design without caps or drop panels provided v is limited to $0.03f'c$. The bending stresses from this departure will be discussed below.

It is impossible to draw any conclusions about the distribution of shear v in the slab since preliminary curves of strain versus gauge positions for the shear reinforcing lead nowhere. This is to be expected since the reinforcing was ineffective. However, the failure cracks give definite indications that the shear v is greatest in the vicinity of the column and that this is the critical area.

BENDING EFFECTS

While the bending effects were not investigated as thoroughly as those for shear, there were sufficient gauge positions to indicate that the distribution of bending stresses is far from uniform. In the area close to the column these stresses are high both in the concrete and steel. The relative overstress of steel is not as great nor as critical as for the concrete, since the steel could be spaced more closely over the column and this would help to produce a more even distribution of steel stresses. Not much can be done for the concrete except to thicken up the slab or to increase the concrete strength. Both are costly. However, in any future work the bending stresses should be more thoroughly investigated. It is possible that even with future success in reinforcing the slab against shear, the bending stresses, because of their unequal distribution across the section, would prevent the use of a shear reinforced flat slab without caps and drops.

The results of both bending and shear indicate the need for future investigation along the following lines:

(a) The high bending stresses suggest that the problem could best be solved for the interior columns by some type of structural shape. This would even out the bending stresses and would increase the area resisting shear.

(b) The comparatively small bending stresses at exterior columns, combined with the difficulty of using a structural shape, suggest that in this area the solution would be to reinforce the slab against shear.

USE OF SR-4 GAUGES IN CONCRETE

The methods used to waterproof the SR-4 Strain Gauges were successful. The gauges showed consistent values. This indicates that they were operating accurately and can be relied upon when used in concrete. The tests do not show whether the interruption of bond due to the waterproofing has any appreciable effects on the results.

LOAD BLOCK

This type of load-measuring device is accurate and dependable, cheap and easy to construct. Its application to other tests should be considered where the specimen must be tested outside of a testing machine.

APPENDIX

In the autumn of 1947, Mr. B. A. Eskenazi cast four concrete beams as preliminary tests to continuing the present work. It was hoped that the results from these beams would show whether a section seven inches thick could be reinforced against diagonal tension, using individual stirrups hooked around the main steel. The plan was to cast four beams. Two were to have no stirrups while two were to be reinforced with stirrups designed to resist a working shear load of 0.06f'c. The beams are shown in Figure A-1.

The beams were poured in sets of two, one beam of each pair being reinforced with stirrups. One SR-4 Gauge was mounted on the shear reinforcing in each beam.

The beams were tested in the Emery Testing Machine by loading the beam as shown in Figure A-1. These beams were loaded to failure, the application of load being continuous.

Table A-1 contains the cylinder strength and ultimate breaking load of the beams. In Figure A-2 the strain readings versus load are plotted for the two beams.

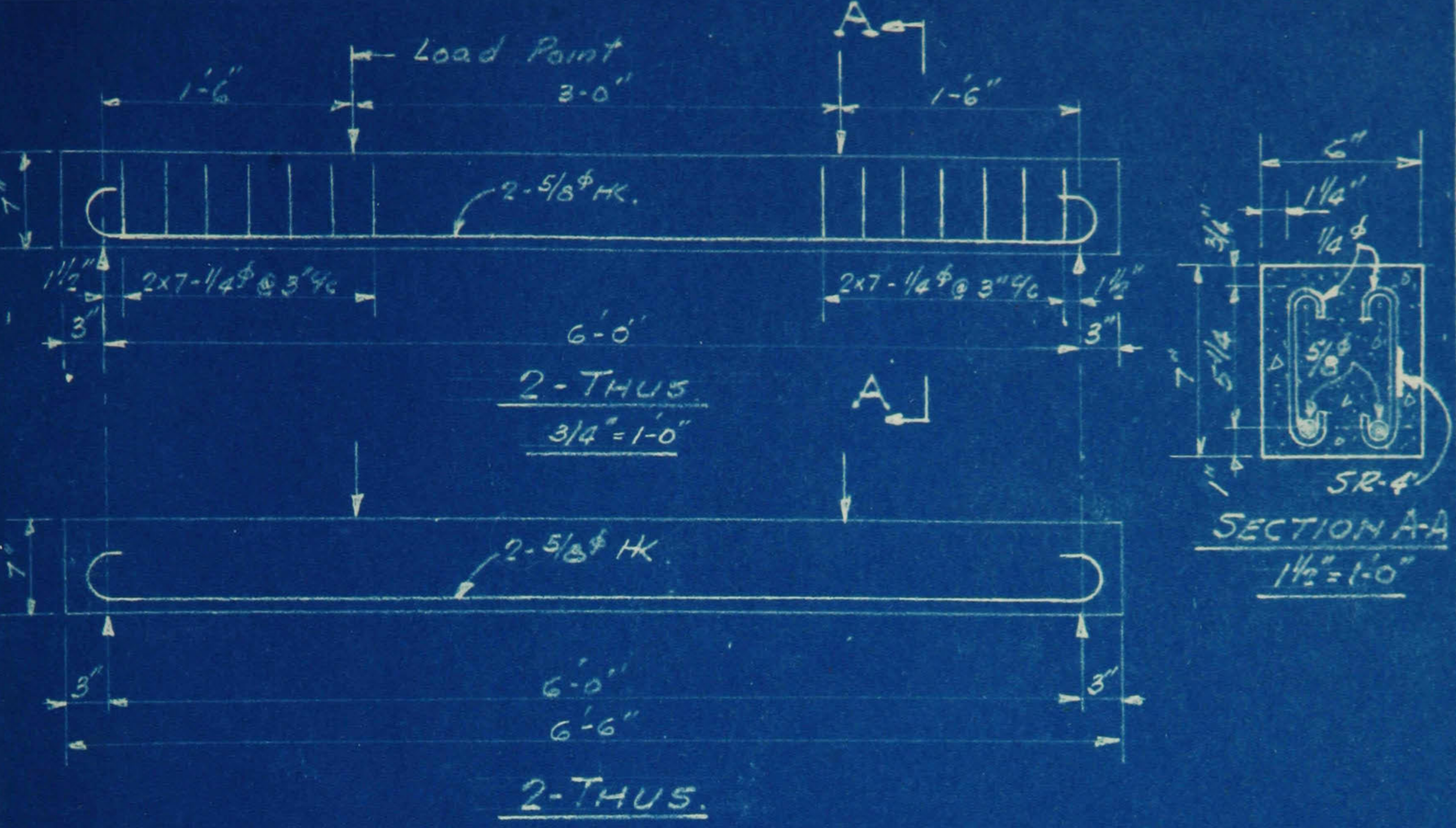
TABLE A-1

Group 1	Ultimate Load	Cylinder Strength
Unreinforced	16400 lb.	79200 lb.
Reinforced	17300 lb.	= 2800 p.s.i.
Group 2		
Unreinforced	15800 lb.	86100 lb.
Reinforced	15100 lb.	= 3050 p.s.i.

From a comparison of the ultimate loads, the results indicate that the shear reinforcing had no effect. The gauges show very little stress in this steel, the maximum stress being only 2910 p.s.i.

The results of these tests reinforce the results obtained from the slabs, namely, that for thin sections stirrups are ineffective as shear reinforcing. The small variation in ultimate load is the usual which can be expected in tests on concrete beams. Even anchoring the stirrups around the tension steel had no effect.

While only four beams were tested, the results definitely show that further investigation is needed on shear reinforcing in thin sections.



DETAIL OF TEST BEAMS.

FIGURE A-1

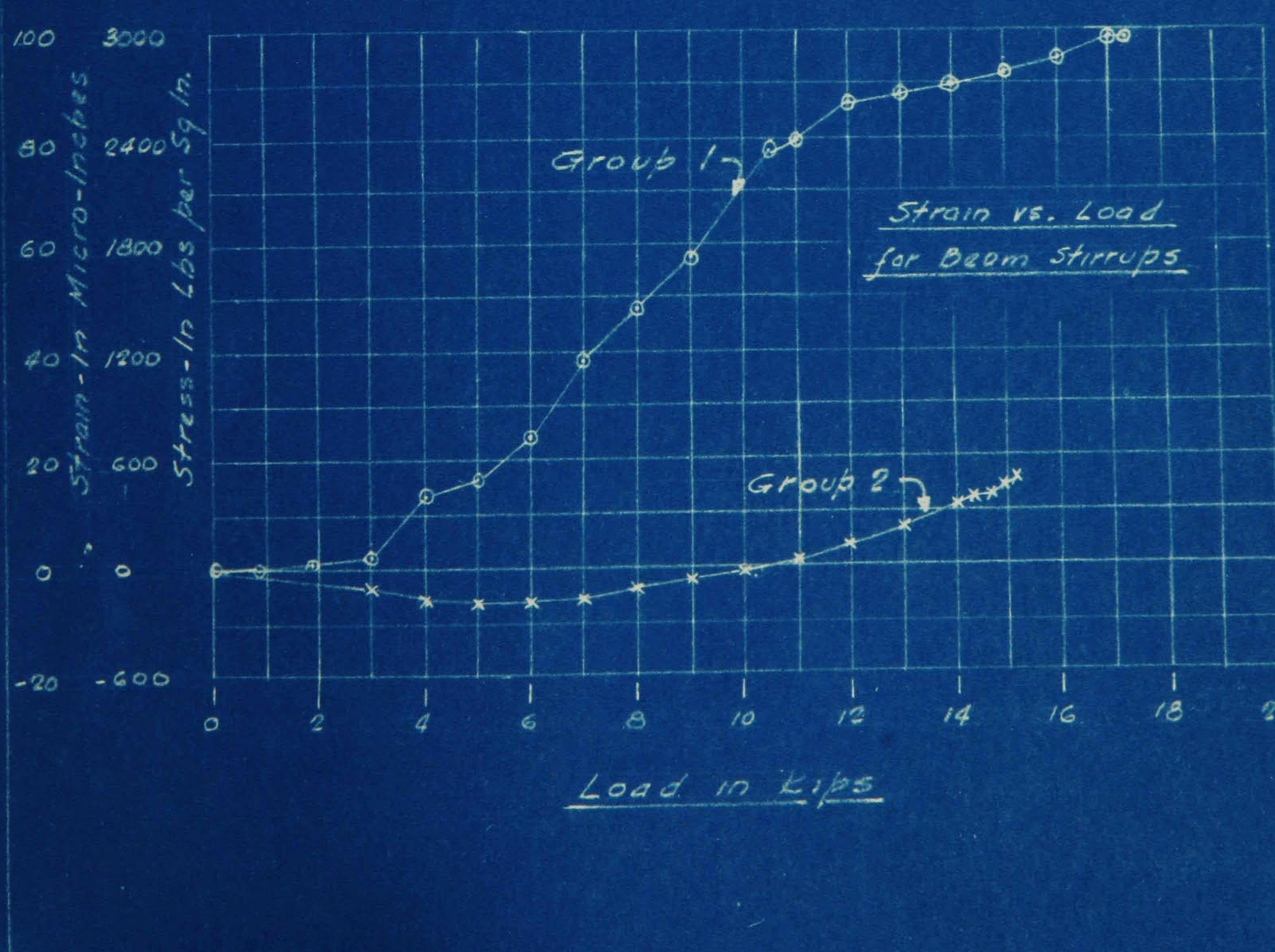


FIGURE - A2

ACKNOWLEDGMENT

Grateful acknowledgment is made to Professor R. E. Jamieson and to Professor G. J. Dodd of the Civil Engineering Department, for their help in planning this work, and to Mr. Tom Pavlasek of the Electrical Engineering Department, who generously helped plan the electrical setup of the SR-4 Gauges.

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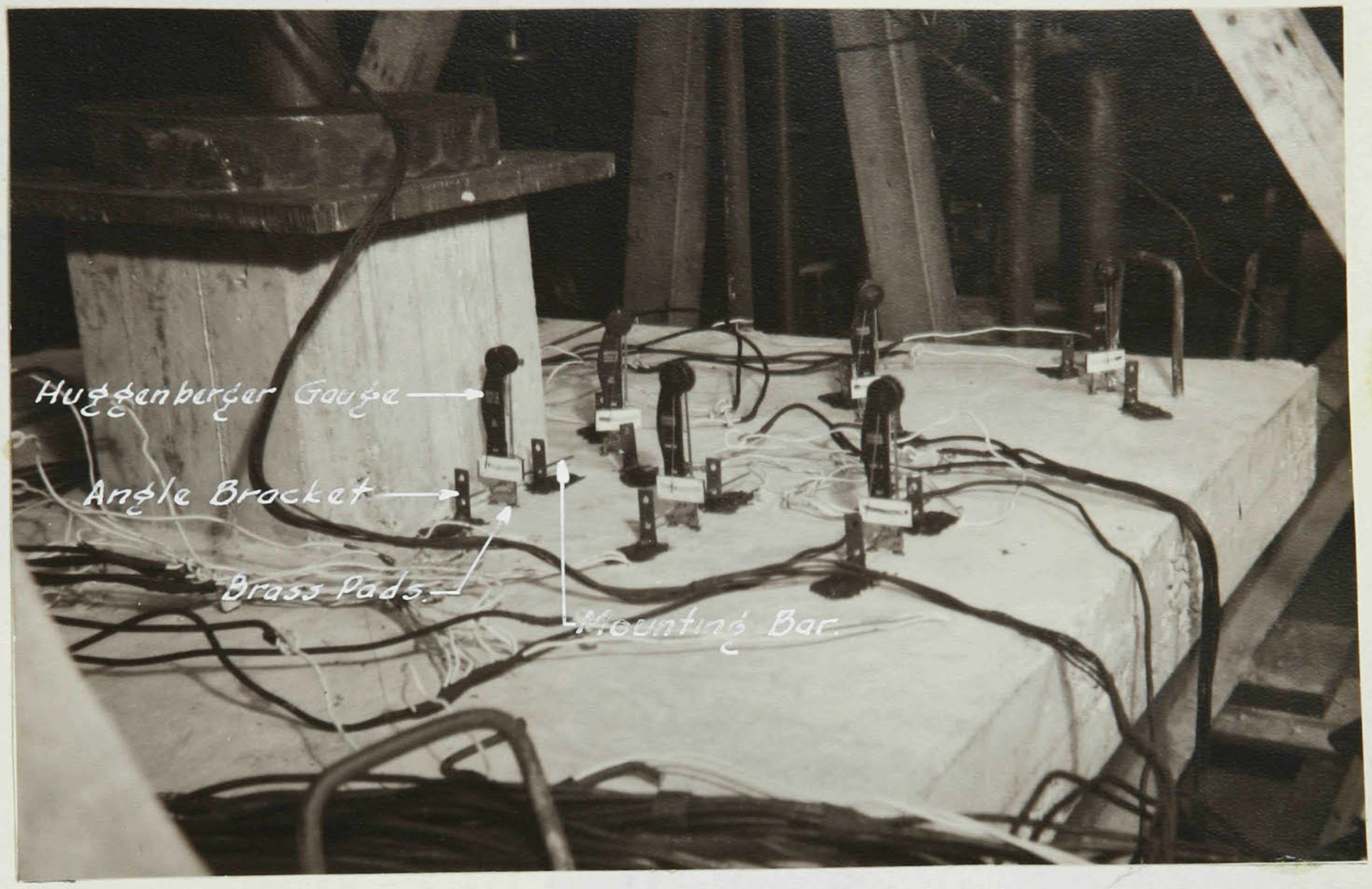


PLATE 2

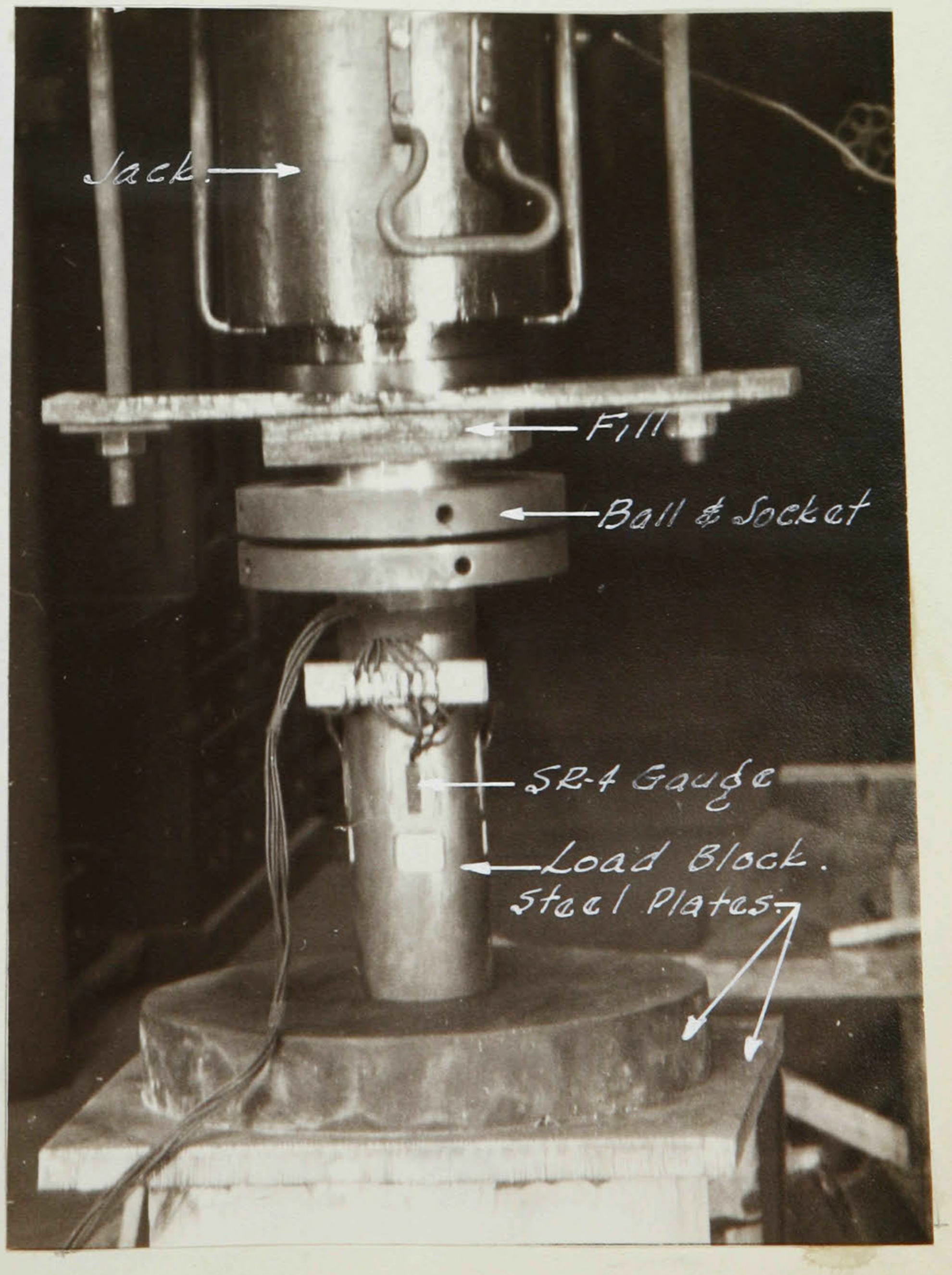
Huggenberger Gauges

PLATE 3

Deflection Scale

PLATE 4

Load Block



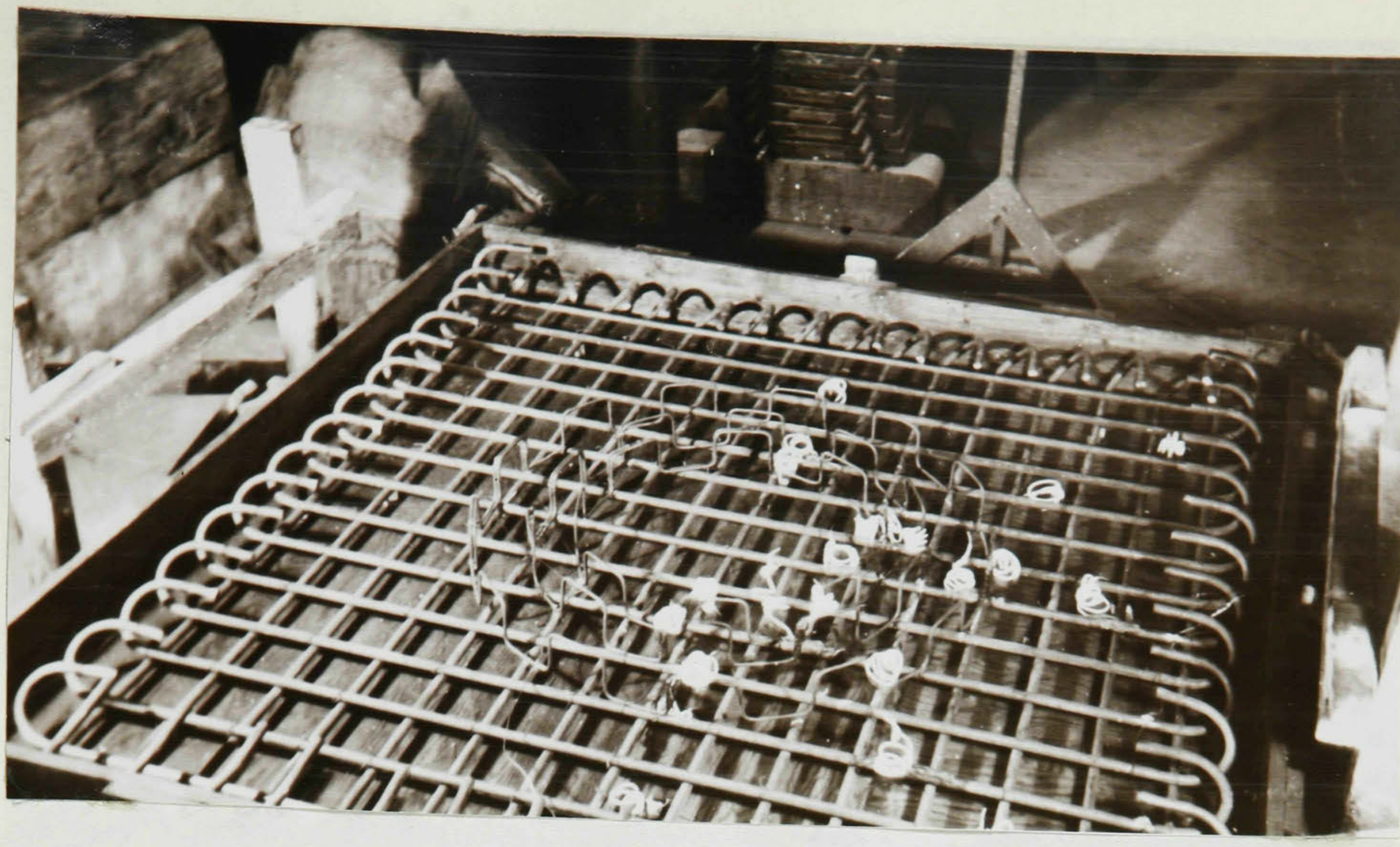


PLATE 5

View of Shear Reinforcing in Place - Slab B

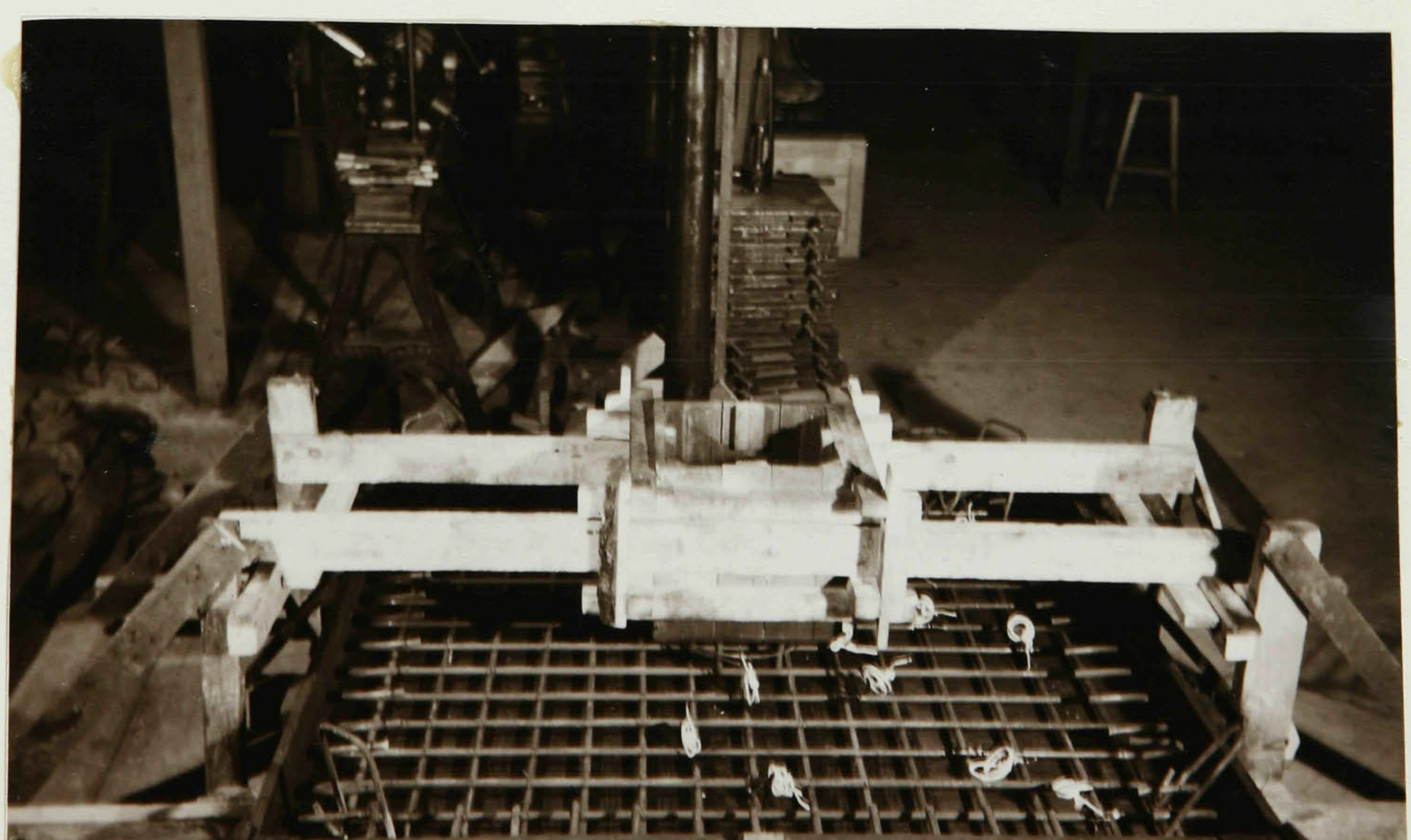


PLATE 6

View of Reinforcing in Forms - Slab E

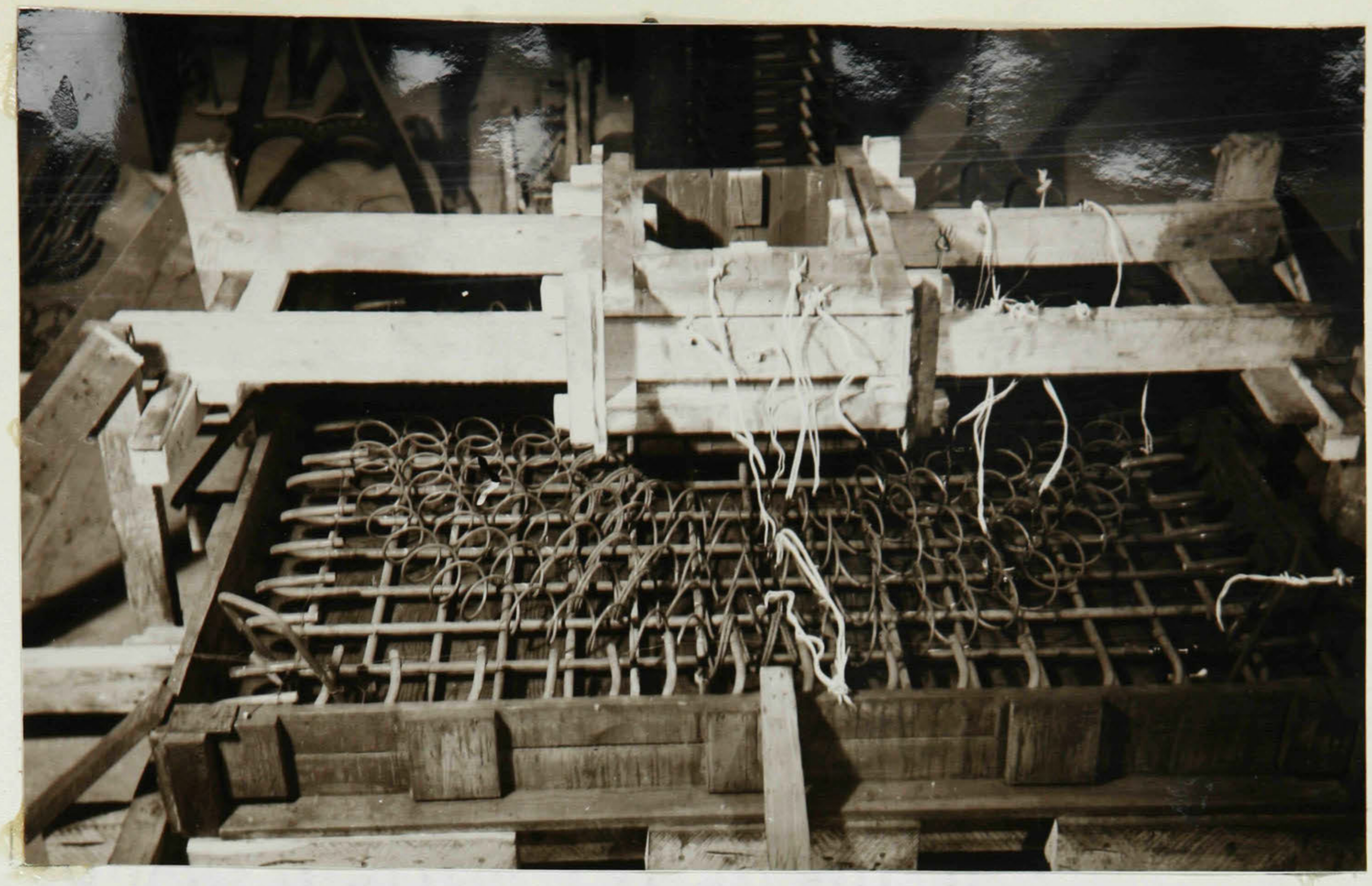


PLATE 7

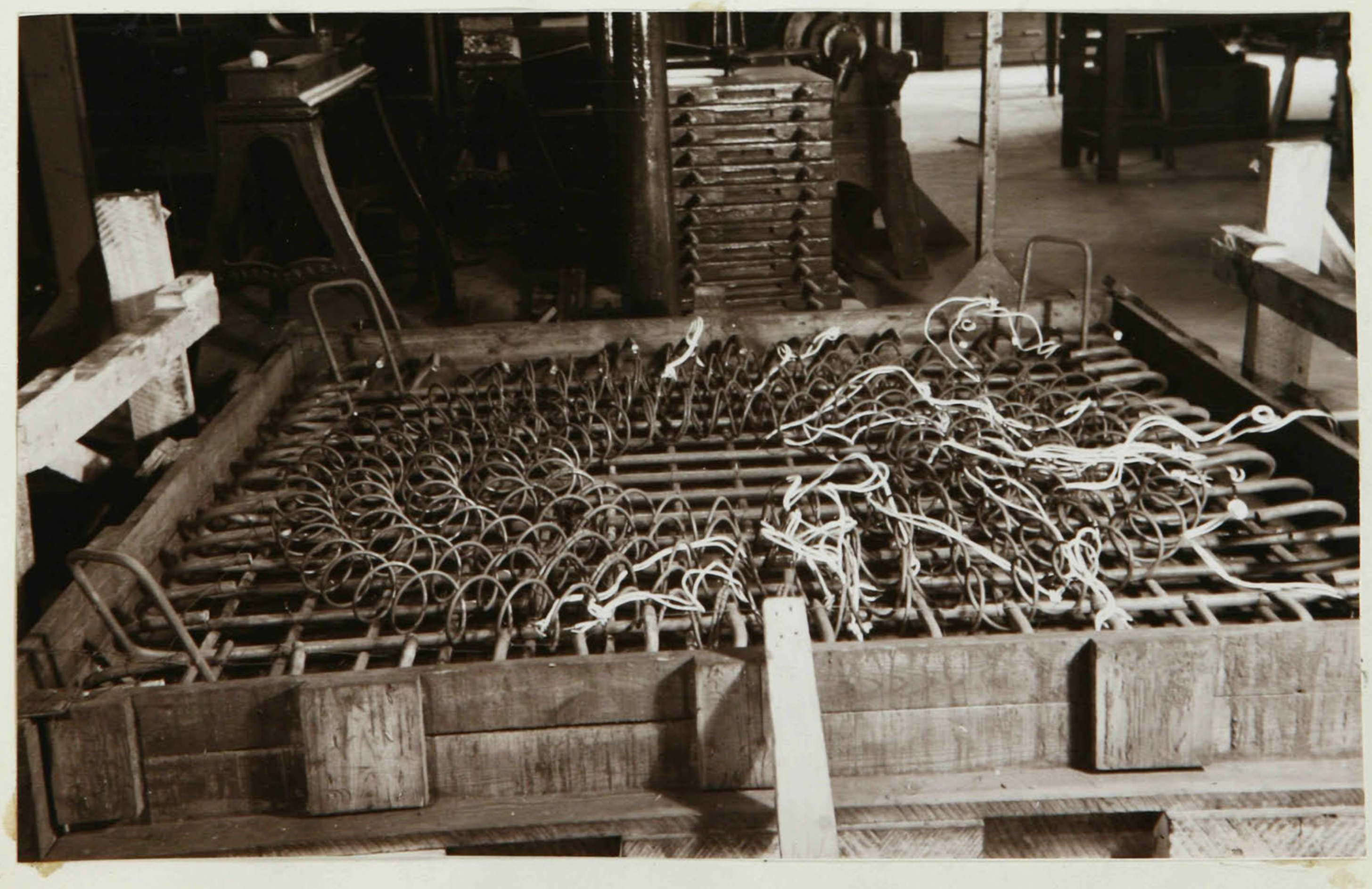


PLATE 8

Plates 7 & 8 - Views of Shear Reinforcing in Place - Slab C

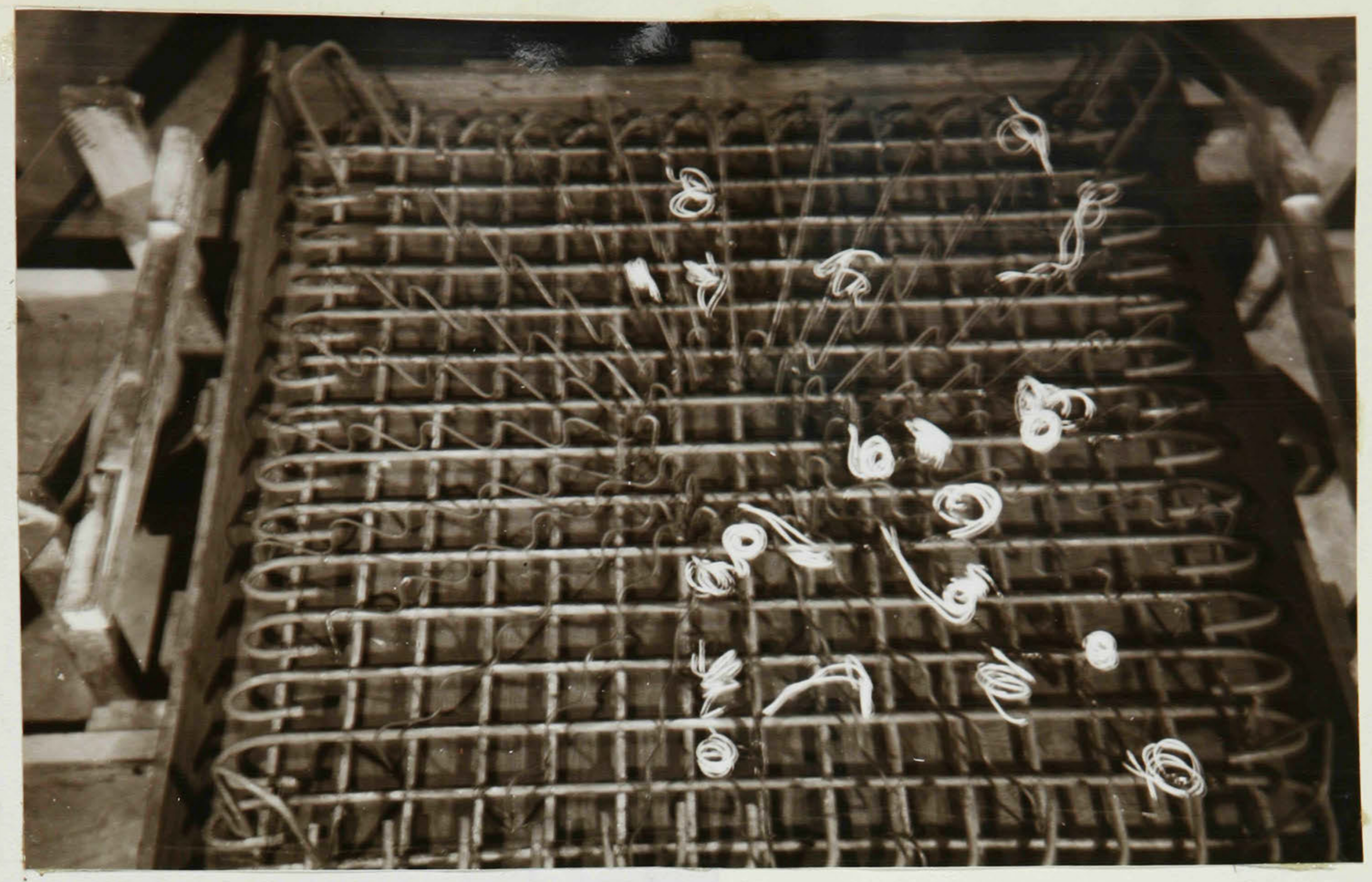


PLATE 9

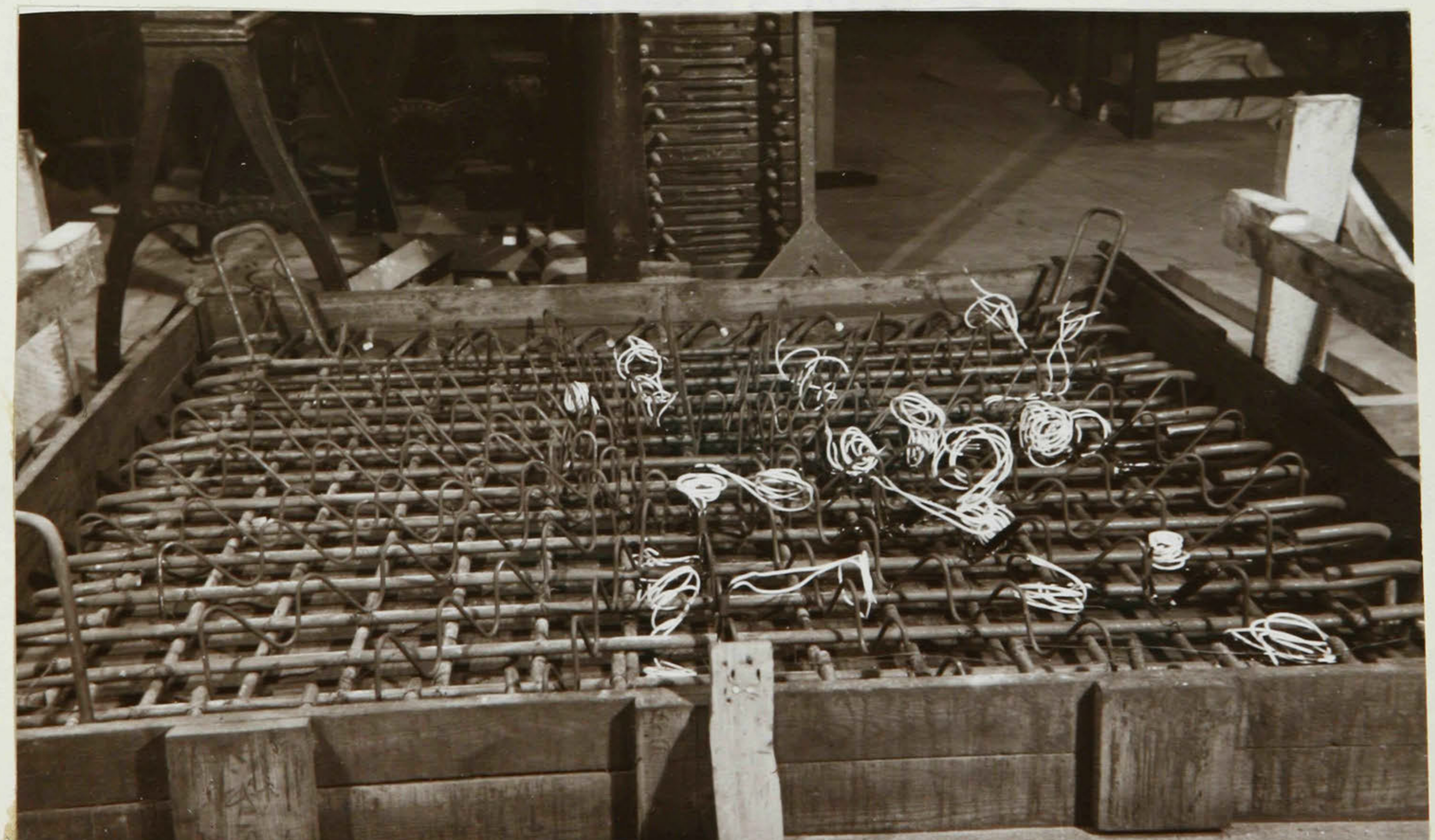


PLATE 10

Plates 9 & 10 - Views of Shear Reinforcing in place - Slab D

PLATE 11

Underside of Slab B

After Failure

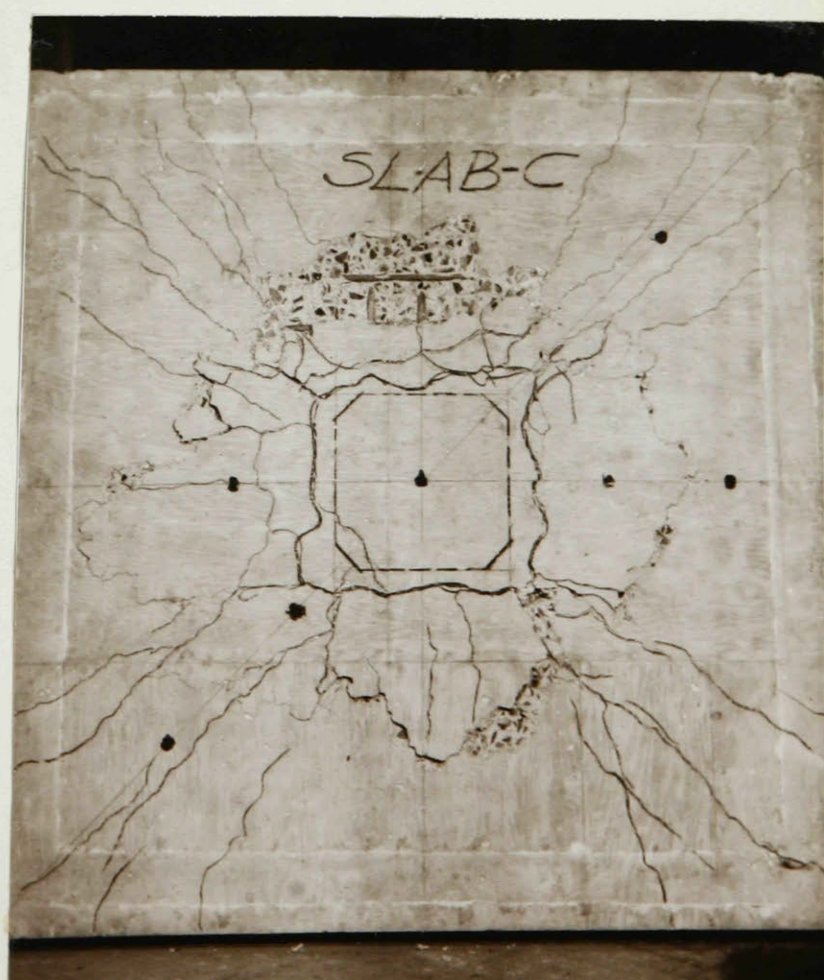


PLATE 12

Underside of Slab C

After Failure

PLATE 13

Underside of Slab D

After Failure

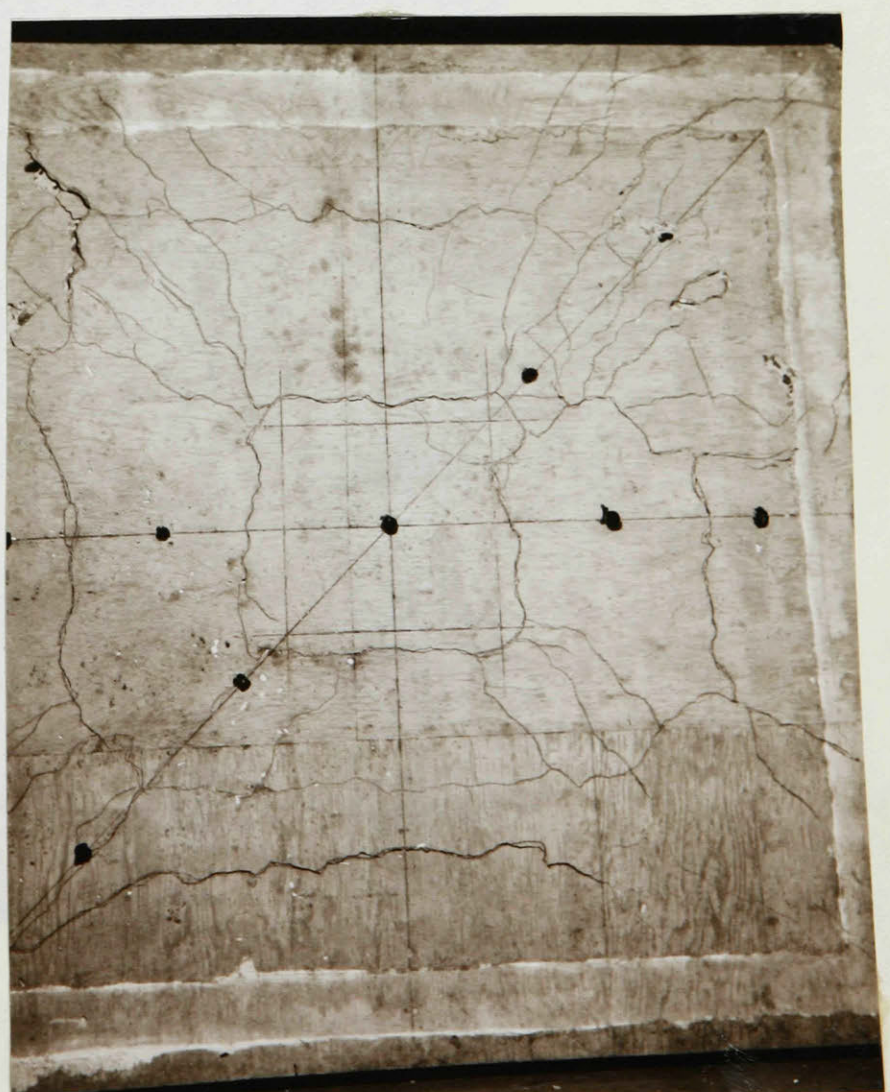


PLATE 14

Underside of Slab E

After Failure

PLATE 15

PLATE 16

Shear Failure on Compression Face of Concrete - Slab D

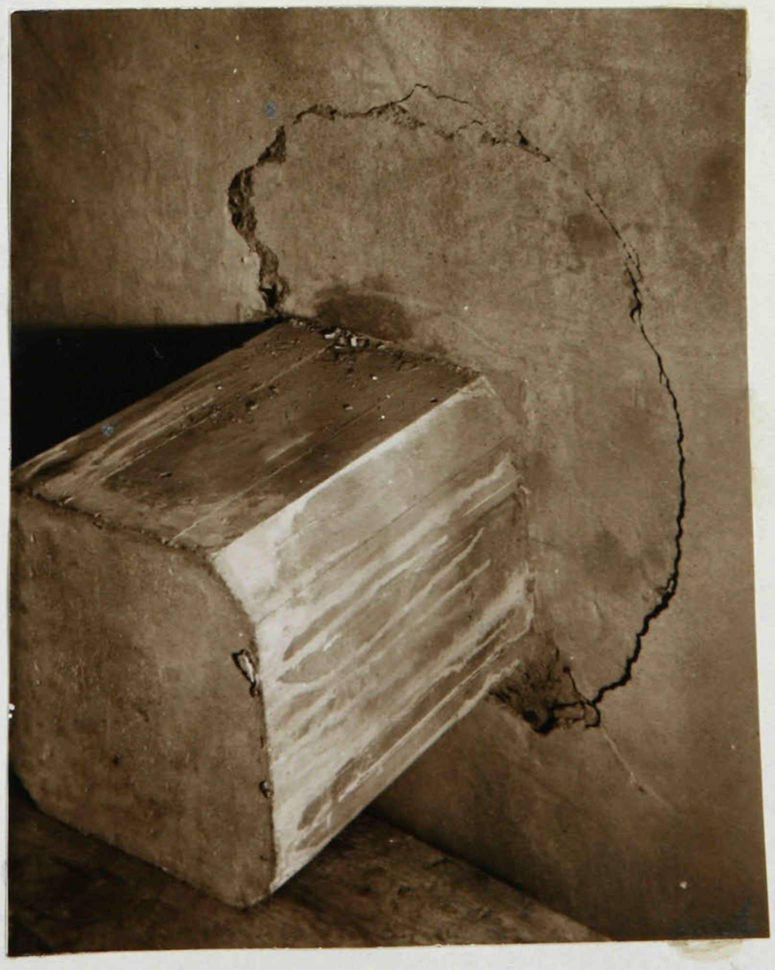


PLATE 17

Shear Failure on Compression Face of Concrete - Slab B

Deflection Scales
Deflection in inches

Load In Kips	GAUGE #2 Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.03	0.04	0.05	0.06	0.04
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.03	0.03	0.02	0.03
20	0.04	0.03	0.06	0.03	0.04	0.04	0.04	0.04	0.06	0.04	0.06	0.04	0.06	0.05	0.05	0.05
30	0.06	0.05	0.06	0.05	0.06	0.06	0.07	0.06	0.08	0.07	0.08	0.06	0.08	0.07	0.08	0.07
40	0.09	0.08	0.08	0.08	0.09	0.09	0.09	0.08	0.10	0.10	0.10	0.08	0.11	0.10	0.10	0.09
50	0.12	0.10	0.11	0.11	0.12	0.11	0.11	0.10	0.13	0.12	0.12	0.10	0.14	0.13	0.12	0.11
60	0.15	0.14	0.14	0.13	0.14	0.13	0.14	0.12	0.15	0.14	0.14	0.12	0.16	0.15	0.14	0.13
70	0.18	0.16	0.17	0.17	0.16	0.15	0.16	0.14	0.18	0.16	0.16	0.14	0.19	0.17	0.16	0.15
80	0.21	0.20	0.20		0.18	0.18	0.18			0.18	0.19		0.21	0.19	0.18	0.17
90		0.22	0.23			0.20	0.20			0.20	0.20		0.24	0.21	0.20	0.19
100													0.27	0.23	0.23	0.22
110													0.31	0.26	0.27	0.26
120													0.37	0.31	0.32	0.30
130													0.52	0.39	0.42	

Load In Kips	GAUGE #4 Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					0.03	0.04	0.04	0.03	0.03	0.04	0.04	0.03	0.05	0.05	0.06	0.04
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.02	0.02	0.03	0.02	0.03	0.02	0.03	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.04	0.03
20	0.02	0.03	0.04	0.04	0.05	0.04	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.06	0.06
30	0.05	0.06	0.06	0.06	0.08	0.07	0.08	0.07	0.08	0.08	0.09	0.07	0.08	0.06	0.09	0.08
40	0.09	0.08	0.09	0.08	0.10	0.09	0.10	0.09	0.11	0.10	0.11	0.10	0.11	0.11	0.11	0.10
50	0.12	0.11	0.12	0.12	0.12	0.12	0.12	0.11	0.13	0.12	0.14	0.12	0.13	0.13	0.14	0.12
60	0.15	0.14	0.15	0.14	0.15	0.14	0.14	0.13	0.15	0.14	0.16	0.13	0.16	0.15	0.16	0.14
70	0.18	0.17	0.18	0.18	0.16	0.16	0.17	0.15	0.17	0.17	0.18	0.15	0.18	0.17	0.18	0.16
80	0.21	0.20	0.21		0.19	0.18	0.19			0.19	0.20		0.21	0.20	0.20	0.18
90		0.23	0.24			0.21	0.21			0.21	0.22		0.24	0.21	0.22	0.21
100													0.27	0.24	0.24	0.24
110													0.31	0.27	0.28	0.28
120													0.36	0.31	0.32	0.32
130													0.53	0.39	0.38	

Deflection Scales
Deflection in inches

Load	GAUGE #3															
	Run 1				Run 2				Run 3				Run 4			
In Kips	B	C	D	E	B	C	D	E	B	C	D	E	B	C	D	E
					0.06	0.06	0.06	0.03	0.06	0.06	0.06	0.03	0.08	0.08	0.08	0.05
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.04	0.04	0.03	0.04	0.04
20	0.05	0.04	0.04	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.08	0.06	0.07	0.06	0.08	0.06
30	0.08	0.07	0.06	0.07	0.09	0.09	0.09	0.08	0.09	0.09	0.10	0.09	0.11	0.10	0.11	0.10
40	0.12	0.10	0.10	0.09	0.12	0.11	0.12	0.11	0.13	0.12	0.13	0.11	0.14	0.13	0.14	0.12
50	0.15	0.13	0.14	0.13	0.14	0.14	0.15	0.14	0.15	0.15	0.16	0.14	0.17	0.16	0.18	0.14
60	0.19	0.17	0.18	0.17	0.17	0.17	0.18	0.16	0.19	0.18	0.19	0.16	0.21	0.19	0.20	0.17
70	0.24	0.22	0.22	0.21	0.20	0.20	0.20	0.18	0.21	0.21	0.22	0.19	0.23	0.21	0.23	0.19
80	0.28	0.26	0.27		0.23	0.23	0.24			0.23	0.25		0.27	0.25	0.26	0.22
90		0.30	0.31			0.26	0.26			0.27	0.27		0.31	0.27	0.28	0.25
100													0.35	0.30	0.32	0.29
110													0.41	0.34	0.37	0.35
120													0.49	0.41	0.44	0.41
130													0.73	0.51	0.60	

Deflection Scales
Deflection in inches

GAUGE #6

Load In Kips	Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					0.00	0.01	0.00	0.00	0.09	0.01	0.01	0.01	0.02	0.01	0.01	0.01
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.01	0.03	0.03	0.02
20	0.01	0.03	0.02	0.02	0.02	0.04	0.04	0.04	0.00	0.04	0.04	0.03	0.01	0.04	0.04	0.04
30	0.03	0.03	0.04	0.04	0.03	0.05	0.06	0.06	0.00	0.06	0.05	0.05	0.02	0.06	0.05	0.06
40	0.05	0.05	0.05	0.05	0.05	0.06	0.07	0.07	0.00	0.06	0.07	0.06	0.04	0.08	0.07	0.07
50	0.06	0.07	0.06	0.07	0.07	0.08	0.08	0.08	0.00	0.08	0.08	0.07	0.05	0.09	0.09	0.08
60	0.07	0.09	0.08	0.08	0.09	0.09	0.10	0.09	0.00	0.09	0.09	0.08	0.07	0.10	0.10	0.09
70	0.09	0.10	0.10	0.10	0.09	0.10	0.11	0.10	0.00	0.10	0.11	0.09	0.07	0.12	0.11	0.10
80	0.10	0.11	0.12		0.11	0.12	0.12			0.12	0.11		0.09	0.13	0.12	0.11
90		0.13	0.12			0.12	0.13			0.12	0.13		0.10	0.14	0.13	0.12
100													0.12	0.15	0.15	0.13
110													0.13	0.16	0.16	0.15
120													0.17	0.18	0.18	0.17
130													0.21	0.21	0.21	

GAUGE #9

Load In Kips	Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.02	0.02	0.02	0.01	0.03	0.02	0.03	0.02	0.03	0.02	0.03	0.02	0.03	0.02	0.03	0.03
20	0.03	0.03	0.04	0.03	0.05	0.04	0.05	0.04	0.06	0.04	0.05	0.04	0.05	0.04	0.05	0.04
30	0.05	0.04	0.05	0.05	0.06	0.05	0.06	0.05	0.06	0.05	0.06	0.05	0.06	0.06	0.07	0.06
40	0.06	0.05	0.06	0.05	0.08	0.06	0.07	0.06	0.08	0.06	0.08	0.06	0.07	0.07	0.08	0.07
50	0.06	0.07	0.08	0.07	0.09	0.08	0.09	0.07	0.09	0.08	0.09	0.07	0.09	0.08	0.09	0.08
60	0.09	0.09	0.09	0.09	0.10	0.09	0.09	0.08	0.10	0.09	0.10	0.08	0.10	0.10	0.11	0.09
70	0.11	0.10	0.10	0.10	0.11	0.10	0.11	0.09	0.11	0.10	0.11	0.10	0.11	0.11	0.12	0.10
80	0.12	0.11	0.12		0.12	0.11	0.12			0.11	0.12		0.13	0.12	0.13	0.11
90		0.12	0.14			0.12	0.13			0.12	0.13		0.14	0.13	0.13	0.12
100													0.15	0.14	0.15	0.14
110													0.17	0.15	0.17	0.16
120													0.19	0.17	0.19	0.17
130													0.25	0.20	0.23	

Deflection Scales
Deflection in inches

Load In Kips	GAUGE #7 Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					0.03	0.05	0.05	0.04	0.04	0.05	0.05	0.04	0.05	0.06	0.06	0.05
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.01	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.03
20	0.04	0.04	0.04	0.04	0.06	0.04	0.05	0.04	0.06	0.05	0.06	0.05	0.05	0.05	0.07	0.05
30	0.06	0.06	0.06	0.06	0.08	0.07	0.08	0.06	0.08	0.08	0.08	0.07	0.08	0.08	0.09	0.08
40	0.10	0.08	0.09	0.09	0.11	0.09	0.10	0.09	0.11	0.10	0.11	0.09	0.11	0.11	0.12	0.10
50	0.12	0.11	0.12	0.12	0.13	0.12	0.12	0.11	0.14	0.12	0.13	0.11	0.14	0.13	0.15	0.12
60	0.16	0.15	0.15	0.15	0.16	0.14	0.14	0.12	0.16	0.15	0.16	0.13	0.16	0.15	0.17	0.14
70	0.19	0.18	0.19	0.18	0.18	0.16	0.17	0.15	0.18	0.17	0.18	0.15	0.19	0.18	0.19	0.16
80	0.22	0.21	0.22		0.20	0.19	0.19			0.19	0.20		0.22	0.21	0.21	0.18
90		0.24	0.25			0.22	0.22			0.22	0.22		0.25	0.22	0.24	0.21
100													0.28	0.25	0.26	0.24
110													0.33	0.28	0.31	0.29
120													0.40	0.33	0.35	0.33
130													0.58	0.41	0.48	

Load In Kips	GAUGE #8 Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					0.04	0.05	0.04	0.03	0.03	0.05	0.05	0.03	0.05	0.07	0.06	0.04
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.02	0.03	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.04	0.04
20	0.03	0.04	0.05	0.04	0.04	0.05	0.06	0.05	0.06	0.06	0.07	0.06	0.07	0.06	0.07	0.06
30	0.06	0.06	0.06	0.06	0.07	0.08	0.09	0.07	0.09	0.09	0.09	0.08	0.09	0.09	0.10	0.09
40	0.09	0.09	0.10	0.08	0.10	0.10	0.12	0.09	0.11	0.12	0.11	0.10	0.12	0.12	0.12	0.11
50	0.13	0.12	0.12	0.12	0.12	0.13	0.14	0.11	0.14	0.14	0.14	0.12	0.15	0.14	0.15	0.13
60	0.16	0.16	0.16	0.14	0.14	0.16	0.16	0.13	0.16	0.16	0.16	0.14	0.18	0.17	0.17	0.15
70	0.19	0.19	0.19	0.18	0.16	0.18	0.18	0.16	0.19	0.19	0.19	0.17	0.21	0.20	0.20	0.17
80	0.22	0.23	0.23		0.19	0.21	0.20			0.22	0.21		0.24	0.22	0.22	0.19
90		0.27	0.26			0.24	0.23			0.24	0.23		0.26	0.24	0.24	0.22
100													0.30	0.27	0.26	0.25
110													0.34	0.30	0.30	0.30
120													0.41	0.36	0.36	0.35
130													0.60	0.44	0.52	

SR-4 Gauges   Slab B: Type A-12-4 G.F. 2.06 ± 1% Res. in ohms 119.6 ± 0.2   Slabs C & D: Type A-1-4 G.F. 2.04 ± 1% Res. in ohms 120.0 ± 0.2

GAUGE #16

Load In Kips	B 1	B 2	B 3	B 4	C 1	C 2	C 3	C 4	D 1	D 2	D 3	D 4	E 1	E 2	E 3	E 4
						-22	-11	-85		-25	13	-85				
0					0	0	0	0	0	0	0	0				
10					2	2	-10	-3	-9	20	10	99				
20					-9	-8	-10	27	23	46	4	113				
30					-13	-12	-11	28	27	-2	-19	118				
40					-17	-16	-29	7	35	75	-5	120				
50	Inoperative				-25	-36	-40	3	33	98	10	106	Not Used In This Slab			
60					-48	-42	-44	-3	37	78	-16	146				
70					-62	-40	-57	-32	96	115	55	178				
80					-62	-83	-69	-25	74	116	34	148				
90					-78	-59	-78	-53	67	139	77	173				
100								-44				182				
110								-50				219				
120								-67				180				
130								-83				199				

All values in micro-inches.

GAUGE #17

Load In Kips	B 1	B 2	B 3	B 4	C 1	C 2	C 3	C 4	D 1	D 2	D 3	D 4	E 1	E 2	E 3	E 4
						-10	0	-55		-2	15	-65				
0					0	0	0	0	0	0	0	0				
10					15	0	-6	-10	1	10	0	70				
20					13	-7	-15	19	14	28	-21	79				
30					11	-19	-16	8	18	-7	-80	79				
40					11	-25	-34	-12	24	33	-19	76				
50	Inoperative				-2	-45	-54	-21	14	48	-18	54	Not Used in This Slab			
60					-35	-53	-65	-32	11	20	-24	73				
70					-55	-59	-76	-60	56	48	3	101				
80					-67	-100	-89	-57	4	40	-17	79				
90					-93	-90	-107	-82	-11	53	-1	89				
100								-77				86				
110								-92				108				
120								-125				79				
130								-177				117				

SR-4 Gauges   Slab B: Type A-12-4 G.F. 2.06 ± 1% Res. in ohms 119.6 ± 0.2   Slabs C & D: Type A-1-4 G.F. 2.04 ± 1% Res. in ohms 120.0 ± 0.2

GAUGE #18

Load	B				C				D				E			
In Kips	1	2	3	4	1	2	3	4	1	2	3	4	1.	2	3	4
		295	-298			-9	5	-55		-9	14	-40				
0	0	0	0		0	0	0	0	0	0	0	0				
10	150	-335	90		1	4	-6	-14	-4	9	8	70				
20	315	-330	233		-7	-1	-10	15	23	32	-14	70				
30	310	-315	253		-20	-9	-6	17	30	6	-57	76				
40	270	-390	468	Inoperative	-25	-8	-19	4	40	55	6	88	Not Used in This Slab			
50	209	-374	633		-28	-19	-24	0	31	73	12	84				
60	180	-525	468		-38	-19	-24	-4	33	60	19	101				
70	180	-355	574		-37	-19	-33	-24	84	89	50	129				
80	250	-326	617		-31	-46	-39	-13	56	90	34	107				
90					-35	-26	-39	-33	46	110	62	128				
100								-18				133				
110								-18				166				
120								-25				156				
130								-35				191				

All values in micro-inches.

GAUGE #19

Load	B				C				D				E			
In Kips	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
		11	29	1778		-4	9	-37		-20	-2	-76				
0	0	0	0	0	0	0	0	0	0	0	0	0				
10	-17	4	9	23	4	6	-4	-16	-20	15	3	63				
20	-23	3	-1	22	-6	3	-5	13	10	31	-8	78				
30	-27	3	5	9	-6	0	0	14	19	10	-50	76				
40	-12	5	6	12	4	8	-9	7	37	48	15	79				
50	-19	5	7	21	9	0	-7	10	30	72	6	80	Not Used in This Slab			
60	-17	5	8	20	-1	3	-5	6	37	47	12	91				
70	-13	6	16	-22	-1	4	-10	-4	83	78	34	119				
80	13	6		20	6	-17	-13	9	54	73	16	97				
90				18	3	3	-13	-10	21	88	39	111				
100				12				9				113				
110				10				6				134				
120				26				-4				118				
130				33				1				150				

SR-4 Gauges   Slab B: Type A-12-4 G.F. 2.06 ± 1%   Slabs C & D: Type A-1-4 G.F. 2.04 ± 1%
Res. in ohms 119.6 ± 0.2   Res. in ohms 120.0 ± 0.2

GAUGE #20

Load In Kips	B 1	B 2	B 3	B 4	C 1	C 2	C 3	C 4	D 1	D 2	D 3	D 4	E 1	E 2	E 3	E 4
		12	22	58		-55	-45	-103		-7	7	-63				
0	0	0	0	0	0	0	0	0	0	0	0	0				
10	-1	5	2	27	0	0	-7	-15	7	4	0	50				
20	-4	7	0	30	-7	-10	-17	3	10	18	-19	63				
30	-4	8	1	20	-8	-27	-28	-5	7	-6	-61	50				
40	12	14	9	22	-14	-42	-55	-30	10	22	-14	59				
50	12	15	10	36	-43	-66	-73	-48	17	52	-15	56				
60	20	20	19	34	-83	-88	-97	-77	33	12	-14	66	*Not Used in This Slab*			
70	27	30	28	0	-122	-107	-125	-114	57	37	0	85				
80	34	31		42	-154	-152	-150	-129	15	32	-17	66				
90				47	-191	-160	-170	-168	-15	47	4	82				
100				47				-188				84				
110				53				-234				108				
120				69				-320				93				
130				6				-492				206				

All values in micro-inches.

GAUGE #21

Load In Kips	B 1	B 2	B 3	B 4	C 1	C 2	C 3	C 4	D 1	D 2	D 3	D 4	E 1	E 2	E 3	E 4
		14	31	1966		-10	0	-58		-10	8	-46				
0	0	0	0	0	0	0	0	0	0	0	0	0				
10	3	6	7	27	-2	2	-5	-16	-10	8	7	49				
20	-2	7	6	31	-7	-2	-8	14	17	27	-8	63				
30	-3	8	9	20	-14	-7	-5	16	30	8	-45	54				
40	12	13	10	24	-4	-8	-18	6	34	43	6	61				
50	7	15	15	38	-1	-15	-19	-3	24	56	6	65				
60	14	16	20	38	-10	-18	-26	-10	20	39	10	71	*Not Used in This Slab*			
70	20	24	29	4	-15	-20	-35	-29	55	65	-73	96				
80	33	26		44	-20	-48	-41	-22	34	61	10	76				
90				48	-35	-35	-47	-42	15	78	34	91				
100				44				-32				97				
110				46				-40				120				
120				60				-57				113				
130				53				-80								

SR-4 Gauges   Slab B: Type A-12-4 G.F. 2.06 ± 1% Res. in ohms 119.6 ± 0.2   Slabs C & D: Type A-[illegible]-4 G.F. 2.04 ± 1% Res. in ohms 120.0 ± 0.2

GAUGE #22

Load In Kips	B 1	B 2	B 3	B 4	C 1	C 2	C 3	C 4	D 1	D 2	D 3	D 4	E 1	E 2	E 3	E 4
		14	20	72		2	13	-22		-14	2	62				
0	0	0	0	0	0	0	0	0	0	0	0	0				
10	3	4	4	24	-8	3	-2	-21	-8	4	2	52				
20	0	3	0	26	-9	-2	-8	2	24	19	-17	62				
30	2	2	0	13	-25	-7	-3	3	37	-5	-55	52				
40	18	4	0	13	-22	-5	-13	-3	57	22	-10	62				
50	10	1	0	21	-22	-12	-12	-8	43	35	-12	57	Not Used in This Slab			
60	10	4	2	18	-29	-12	-15	-13	27	16	-8	62				
70	10	6	9	-29	-25	-13	-21	-27	55	41	6	85				
80	18	6		18	-18	-37	-32	-22	17	36	-15	66				
90				20	-20	-21	-32	-39	-10	51	8	78				
100				13				-28				82				
110				11				-32				105				
120				26				-47				93				
130				21				-86								

All values in micro-inches.

GAUGE #23

Load In Kips	B 1	B 2	B 3	B 4	C 1	C 2	C 3	C 4	D 1	D 2	D 3	D 4	E 1	E 2	E 3	E 4
		-21	62	824		-4	1	-41		-20	-9	2				
0	0	0	0	0	0	0	0	0	0	0	0	0				
10	2	53	5	23	-1	3	0	-13	-4	2	-1	47				
20	2	53	0	23	-4	2	0	12	18	12	-16	57				
30	1	53	8	10	-6	2	7	19	25	-11	-56	48				
40	17	56	4	11	6	5	0	11	42	13	-18	50				
50	10	53	9	21	10	2	5	12	6	21	-23	48	Not Used in This Slab			
60	15	58	10	18	1	4	2	14	-12	0	-19	50				
70	20	63	19	-14	3	7	0	1	15	20	-13	70				
80	32	64		23	8	-12	-3	11	-15	16	-35	50				
90				24	3	5	-2	-1	-45	28	-13	66				
100				14				11				70				
110				16				9				91				
120				28				-9				105				
130				34				-78								

SR-4 Gauges   Slab B: Type A-12-4 G.F. 2.06 ± 1%   Slabs C & D: Type A-1-4 G.F. 2.04 ± 1%
Res. in ohms 119.6 ± 0.2   Res. in ohms 120.0 ± 0.2

Load In Kips	GAUGE #24 B 1	B 2	B 3	B 4	C 1	C 2	C 3	C 4	D 1	D 2	D 3	D 4	E 1	E 2	E 3	E 4
						4	12	-26		-30	-27	-94				
0					0	0	0	0	0	0	0	0				
10					0	1	-2	-16	96	-4	-2	42				
20					-5	-2	-4	7	130	-4	-32	37				
30					-9	-3	1	11	148	-44	-109	1				
40					1	0	-6	6	116	-29	-70	-17				
50					4	-3	-2	8	60	-16	-64	-17				
60	*Not Used in This Slab*				-3	-2	-4	8	30	-10	-25	22	*Not Used in This Slab*			
70					0	0	-8	-7	67	58	27	102				
80					5	-14	-10	5	68	111	57	142				
90					7	1	-8	-9	66	159	130	202				
100								7				217				
110								11				150				
120								17				93				
130								18								

All values in micro-inches.

SR-4 Gauges Type A-1 Gauge Factor 2.05 ± 1%
Resistance in ohms 120.0 ± 0.2

GAUGE #A-1

Load	Run 1				Run 2				Run 3				Run 4			
In Kips	B	C	D	E	B	C	D	E	B	C	D	E	B	C	D	E
					13	5	-7	-9	28	8	-34	-7	-106	2	-44	8
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	8	19	61	0	15	11	10	13	12	12	30	8	38	19	30	12
20	13	27	14	11	33	28	10	27	26	20	54	22	48	21	40	25
30	21	25	24	24	43	33	35	42	39	40	61	40	47	38	72	32
40	48	48	34	42	56	48	25	55	50	48	60	53	59	53	63	43
50	49	65	50	60	67	63	57	75	61	56	93	67	70	64	110	68
60	63	83	50	74	85	77	63	82	78	74	103	85	90	79	119	78
70	83	95	65	90	96	85	41	102	90	75	118	101	97	90	130	96
80	43	110	93		115	100	97			102	114		123	103	140	111
90		129	103			123	113			113	134		140	96	147	122
100													135	138	132	138
110													166	150	187	159
120													195	154	170	178
130													230	171	217	

All values in micro-inches.

GAUGE #A-5

Load	Run 1				Run 2				Run 3				Run 4			
In Kips	B	C	D	E	B	C	D	E	B	C	D	E	B	C	D	E
					10	6	-4	-3	25	7	-23	-5	-71	6	-40	8
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	13	16	6	-2	13	11	8	11	12	12	22	6	33	14	26	10
20	25	28	16	16	32	32	10	28	21	23	47	27	46	22	41	25
30	37	33	30	31	45	40	38	43	39	46	59	44	44	42	76	38
40	160	58	46	50	62	48	32	57	55	59	61	57	64	58	69	52
50	67	78	66	69	75	72	66	71	65	67	96	73	78	70	116	68
60	87	98	71	84	94	91	77	89	80	86	109	85	95	84	130	82
70	105	113	86	100	106	100	65	102	97	94	125	106	104	100	140	98
80	107	128	118		125	115	70			116	123		130	113	154	104
90		148	131			140	134			129	146		146	105	164	130
100													144	150	143	144
110													168	162	208	170
120													196	180	191	190
130													226	207	230	

SR-4 Gauges Type A-1 Gauge Factor 2.05 ± 1%
Resistance in ohms 120.0 ± 0.2

GAUGE #A-2

Load in Kips	Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					15	13	-10	-9	32	10	-27	-10	-26	8	-49	2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	23	29	10	1	27	21	28	24	21	28	35	20	49	32	47	27
20	33	48	30	22	55	53	35	49	45	48	72	48	71	49	71	50
30	53	60	52	46	78	71	72	74	73	84	92	75	80	81	117	74
40	97	98	75	79	107	101	78	99	101	106	105	103	106	110	121	99
50	110	131	105	113	130	125	120	127	124	126	150	132	134	133	180	131
60	140	163	123	143	161	157	140	158	153	158	175	160	170	162	206	159
70	175	190	150	176	190	178	135	187	183	174	200	192	193	190	228	193
80	148	218	191		221	210	204			216	209		231	222	254	218
90		254	215			245	231			238	247		262	225	276	246
100													279	282	277	276
110													323	310	349	313
120													377	342	345	350
130													431	375	408	

All values in micro-inches.

GAUGE #A-6

Load in Kips	Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					10	6	-10	-8	25	6	-28	-10	-57	4	-40	2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	23	24	12	6	28	26	24	28	25	28	39	25	42	46	40	29
20	48	46	37	36	60	60	44	60	51	53	80	60	65	53	68	56
30	80	65	61	61	90	84	84	87	84	93	105	89	82	88	118	84
40	119	110	95	97	120	116	84	116	114	118	122	116	114	118	124	110
50	137	146	130	132	147	144	142	140	135	139	172	145	140	142	188	140
60	168	182	151	160	175	178	168	170	165	172	200	170	177	173	215	165
70	200	213	180	191	202	198	170	197	194	196	228	202	197	200	240	195
80	218	242	225		231	231	236			231	240		237	229	270	221
90		274	254			268	265			254	278		266	233	293	250
100													280	292	290	280
110													315	319	369	320
120													358	352	365	356
130														397	420	

SR-4 Gauges   Type A-1   Gauge Factor 2.05 ± 1%
Resistance in ohms 120.0 ± 0.2

GAUGE #A-3

Load In Kips	Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					17	11	-7	-2	32	12	-26	-3	-94	12	-47	7
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	29	42	19	15	43	45	46	42	40	51	59	33	69	52	69	46
20	49	66	50	48	84	93	74	80	78	84	115	82	104	85	111	86
30	82	96	89	89	121	125	124	121	120	135	148	122	131	134	176	128
40	140	150	136	140	168	170	140	165	162	172	179	168	171	180	194	170
50	172	202	184	192	207	208	206	210	203	204	241	210	315	218	272	217
60	222	252	221	239	250	255	242	250	246	254	279	251	269	262	313	259
70	272	296	261	296	394	289	259	297	290	290	321	304	304	304	350	308
80	262	337	323		340	339	336			338	342		355	350	396	345
90		389	364			387	377			374	397		401	368	430	390
100													441	440	446	435
110													602	482	540	492
120													576	535	546	550
130													630	584	620	

All values in micro-inches.

GAUGE #A-7

Load In Kips	Run 1 B	Run 1 C	Run 1 D	Run 1 E	Run 2 B	Run 2 C	Run 2 D	Run 2 E	Run 3 B	Run 3 C	Run 3 D	Run 3 E	Run 4 B	Run 4 C	Run 4 D	Run 4 E
					13	9	-5	-6	28	8	-22	-7	-107	7	-37	10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	35	36	20	16	46	44	44	51	42	49	60	41	62	50	61	47
20	70	66	58	60	97	97	83	95	85	89	120	96	105	84	113	89
30	123	97	98	95	140	136	138	132	133	144	161	140	132	138	179	136
40	180	159	145	145	188	180	157	172	181	184	191	179	183	185	199	174
50	213	210	196	186	227	220	220	210	217	219	254	217	225	225	279	216
60	260	266	233	234	269	270	257	251	262	267	295	254	277	268	321	253
70	310	315	278	284	312	307	277	290	303	307	337	301	313	312	360	295
80	343	359	341		357	356	354			354	358		370	358	403	330
90		410	385			407	397			391	410		413	375	438	374
100													453	449	448	416
110													499	492	546	472
120													563	550	557	526
130													611	598	622	

SR-4 Gauges Type A-1 Gauge Factor 2.05 ± 1%
Resistance in ohms 120.0 ± 0.2

GAUGE #A-4

Load In Kips	Run 1				Run 2				Run 3				Run 4			
	B	C	D	E	B	C	D	E	B	C	D	E	B	C	D	E
					15	2	-15	-7	30	7	-34	-5	-79	4	-54	6
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	30	40	17	18	50	62	61	63	50	65	81	55	72	66	85	66
20	50	64	.57	59	97	116	100	113	90	107	142	111	110	109	140	114
30	87	94	.95	105	140	156	158	155	143	165	184	157	145	163	219	165
40	157	155	144	160	196	201	175	199	195	206	218	205	199	220	234	210
50	197	211	197	215	241	245	244	245	237	243	284	250	248	260	317	259
60	255	265	240	271	290	295	285	292	285	391	326	295	310	306	361	302
70	313	317	288	330	339	332	306	338	336	335	372	346	347	351	404	352
80	310	366	354		390	386	385			384	394		403	399	447	394
90		428	404			438	430			424	449		454	418	485	444
100													499	493	499	496
110													563	540	604	566
120													642	603	616	633
130													696	666	699	

All values in micro-inches.

GAUGE #A-8

Load In Kips	Run 1				Run 2				Run 3				Run 4			
	B	C	D	E	B	C	D	E	B	C	D	E	B	C	D	E
					15	23	-3	1	27	18	-17	-1	-75	13	-35	11
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	41	41	29	21	62	55	58	60	60	58	74	52	78	61	75	66
20	82	74	65	65	120	113	102	109	115	107	140	116	128	110	134	114
30	142	113	107	108	170	157	156	151	170	166	183	164	164	168	204	164
40	206	178	157	161	224	205	182	196	221	212	216	208	225	227	233	208
50	245	237	210	210	270	251	246	236	265	251	282	250	271	267	313	253
60	307	300	252	265	314	306	288	283	311	307	324	290	330	317	357	293
70	357	358	304	324	362	346	310	326	360	348	368	238	376	365	400	341
80	397	410	370		413	403	388			401	392		437	418	443	379
90		469	422			455	433			446	445		492	440	482	428
100													543	516	495	470
110													598	564	600	535
120													671	631	615	591
130													724	687	687	

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