A MODEL STUDY OF HORIZONTAL PRESSURES ON A RETAINING WALL DUE TO CONCENTRATED SURFACE LOADS AND ELECTRICAL STRAIN GAUGE PRESSURE MEASUREMENT

Presented as partial credit for the Degree of Master of Science in Civil Engineering

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ILLUSTRATIONS AND GRAPHS

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OBJECTIVES AND SCOPE

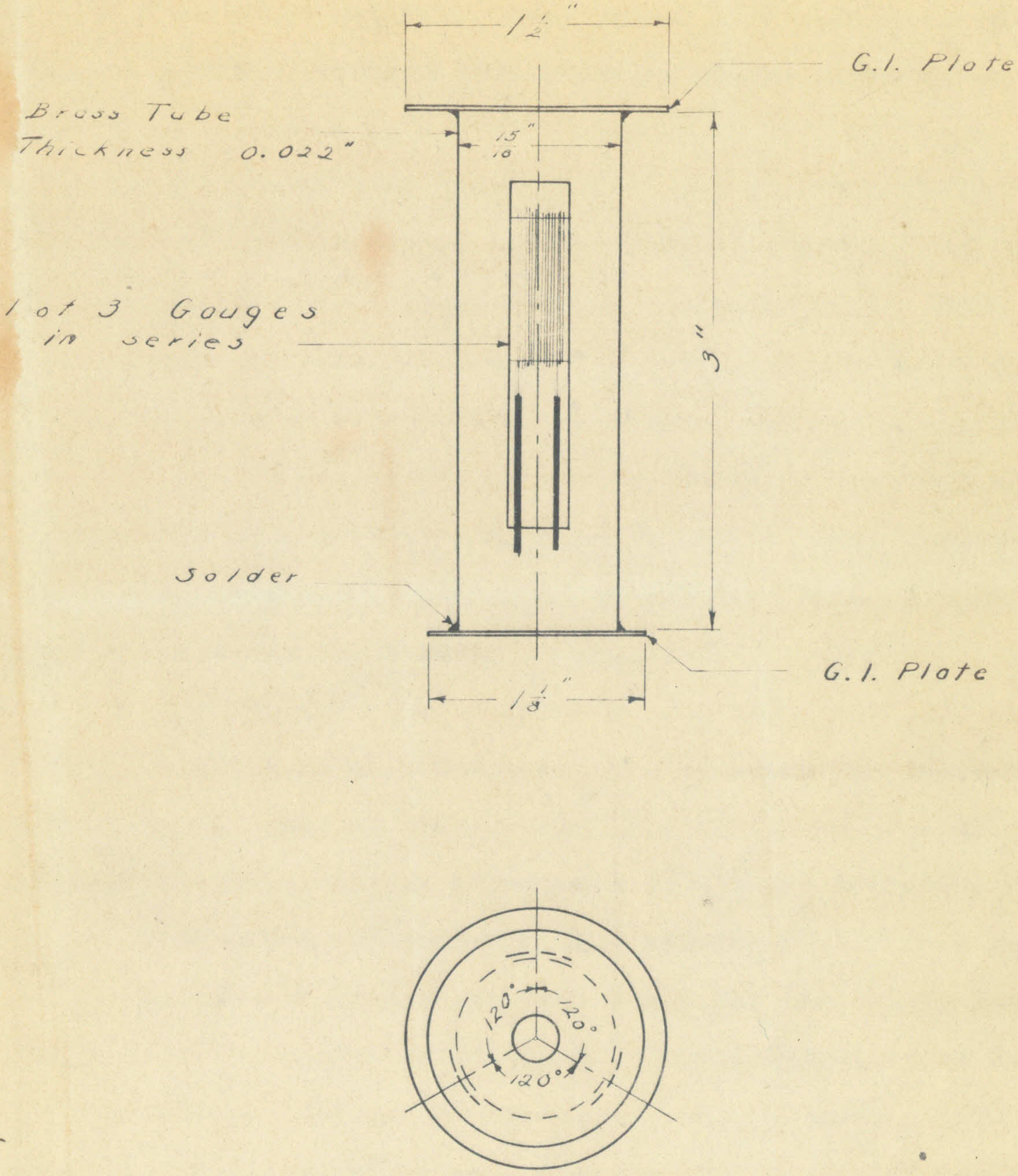
At the onset the objective of this research waa to measure the distribution of horizontal pressures against a model retaining wall with the application of a concentrated or point load at the surface and near the wall. However, as the work progressed and with the decision to attempt to utilize electrical strain gauges for pressure measurement, the objective was expanded. To our knowledge these gauges had not been used before in a similar capacity; therefore, the objective also became that of testing the gauges in this capacity. It must be realized that the original objective was foremost and will receive more consideration.

Due to the comparatively few tests that were performed and the conditions of these tests, the results should have no general significance. At the time of the writing, tests are being made; and more conclusive results may ultimately be reached. Also, since the work was done with a model, the necessity of proper corrections for application to working conditions is apparent.

EQUIPMENT

The equipment may be classed in three more or less distinct groups. They are the gauge assenblies, bridge, and electrical system; the test box and frame; and the loading device.

The gauge assemblies were the most difficult and troublesome phase of all the equipment to develop and put into opera-



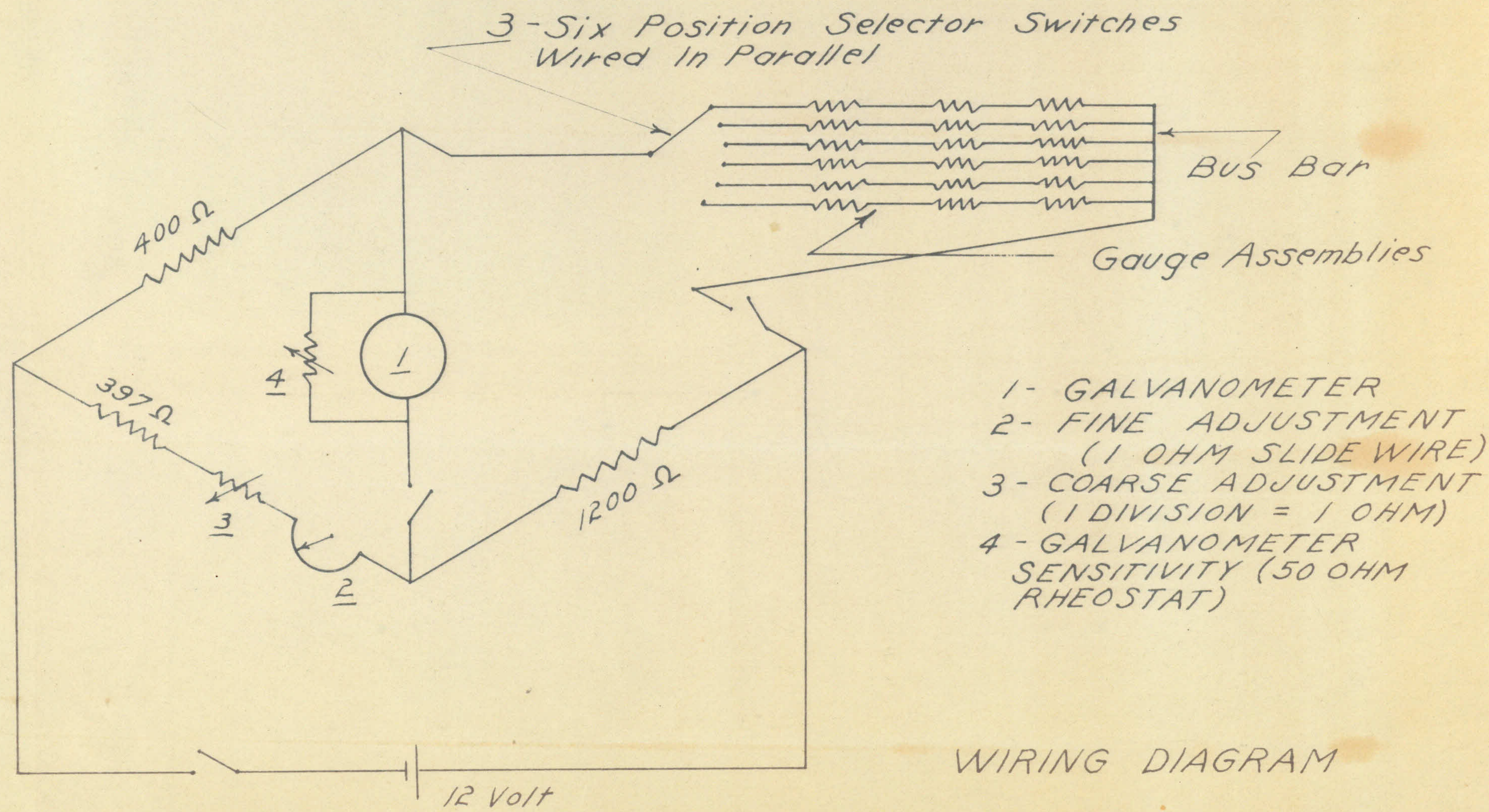
GAUGE ASSEMBLY
DETAIL

Scale: 1" = 1"

Figure 1

tion. Each gauge assembly consisted of a thin-walled brass tube with two galvanized iron circular plates soldered on the ends. Cemented with glyptal cement to the tube in a longitudinal direction, symmetrically spaced, were three 400 ohm aircraft strain gauges made by Douglas Aircraft Company. The gauges were wired in series and the ends wrapped with silk thread and cemented down. The series wiring was decided on for greater sensitivity, simplicity of switching, and the fact that three gauges in series tended to iron out any irregularities due to bending stress. Six of these assemblies were made up and installed in the test box. A drawing of a gauge assembly is shown in Figure 1.

The bridge consisted of two 400 ohm legs, two 1200 ohm legs with a twelve volt battery and a galvonometer connected across them. One of the 400 ohm legs consisted of a 397 ohm resistance, a coarse adjustment of one ohm division, and a fine slide wire adjustment with a vernier dial. This part of the bridge had been previously built for use in the Testing Materials Laboratory of the California Institute of Technology. Any of the gauge assemblies could be made a 1200 ohm leg. The assemblies were switched in and out of the circuit by a six-position selector switch. This switch consisted of three selector switches mounted on the same shaft wired in parallel. This parallel wiring served to minimize switching resistance. The wiring diagram is shown in Figure 2. Figure 3 is a photograph of the bridge.



WIRING DIAGRAM

Figure 2

Figure 3

Figure 4

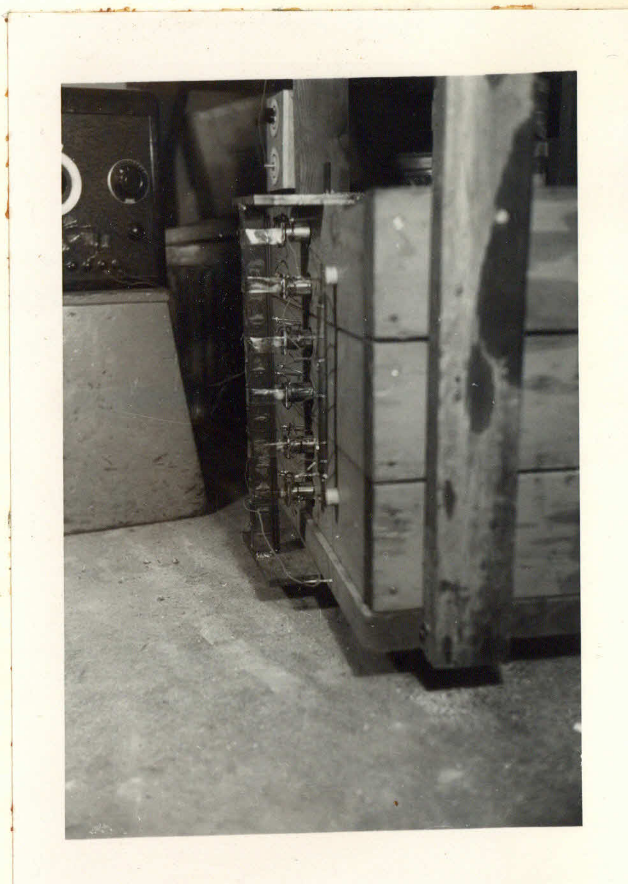


Figure 5

The test box is a box made of 2x6 planks spiked together with screwed angle-iron corner reinforcements. The box measures sixteen and one-half inches deep and twenty-four by twenty-four inches in plan view. Above this is a frame of three 6 inch "I" beams supported on four 2x4 columns. This frame carried the load from the jack to the soil. The whole device is about three feet wide, three feet long and four and one-half feet high. Figures 4 and 6 show the box and frame.

In one side of the box six one-and-one-half inch holes were drilled to house the gauge assemblies. In line with these holes on the outside of the box, was a gauge assembly support (see Figure 8) made of a one-and-one-fourth inch square reinforcing bar, ground smooth on one side and welded to two steel plates which were fastened by screws to the box.

The gauge assemblies were passed through the holes, small end toward the support, and held up by smooth-headed tacks in the holes and by wire strips on the outside of the box. A marble held in place by tape was used to insure central loading of the gauge assemblies and shims were used to make the face of the assemblies flush with the inside of the box. A strip of heavy paper was taped to the inside face of the wall over the assemblies to protect them from soil particles. Photographs of the installed gauge assemblies are shown in Figures 5 and 7.

The loading device consisted of a thirty ton capacity "Black Hawk" hydraulic jack, with a beam gauge to measure the load. The jack was placed on a pile of six inch diameter

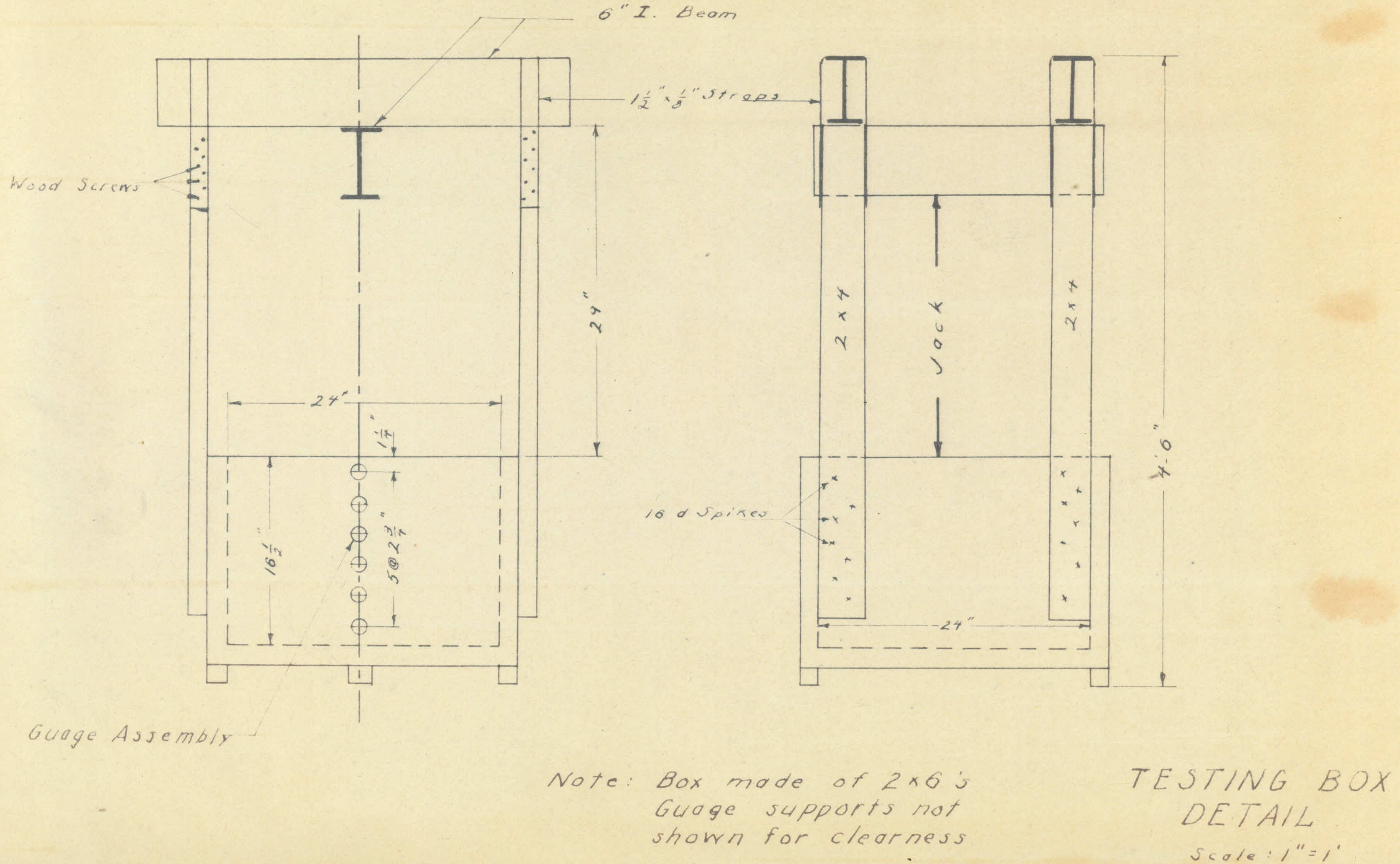
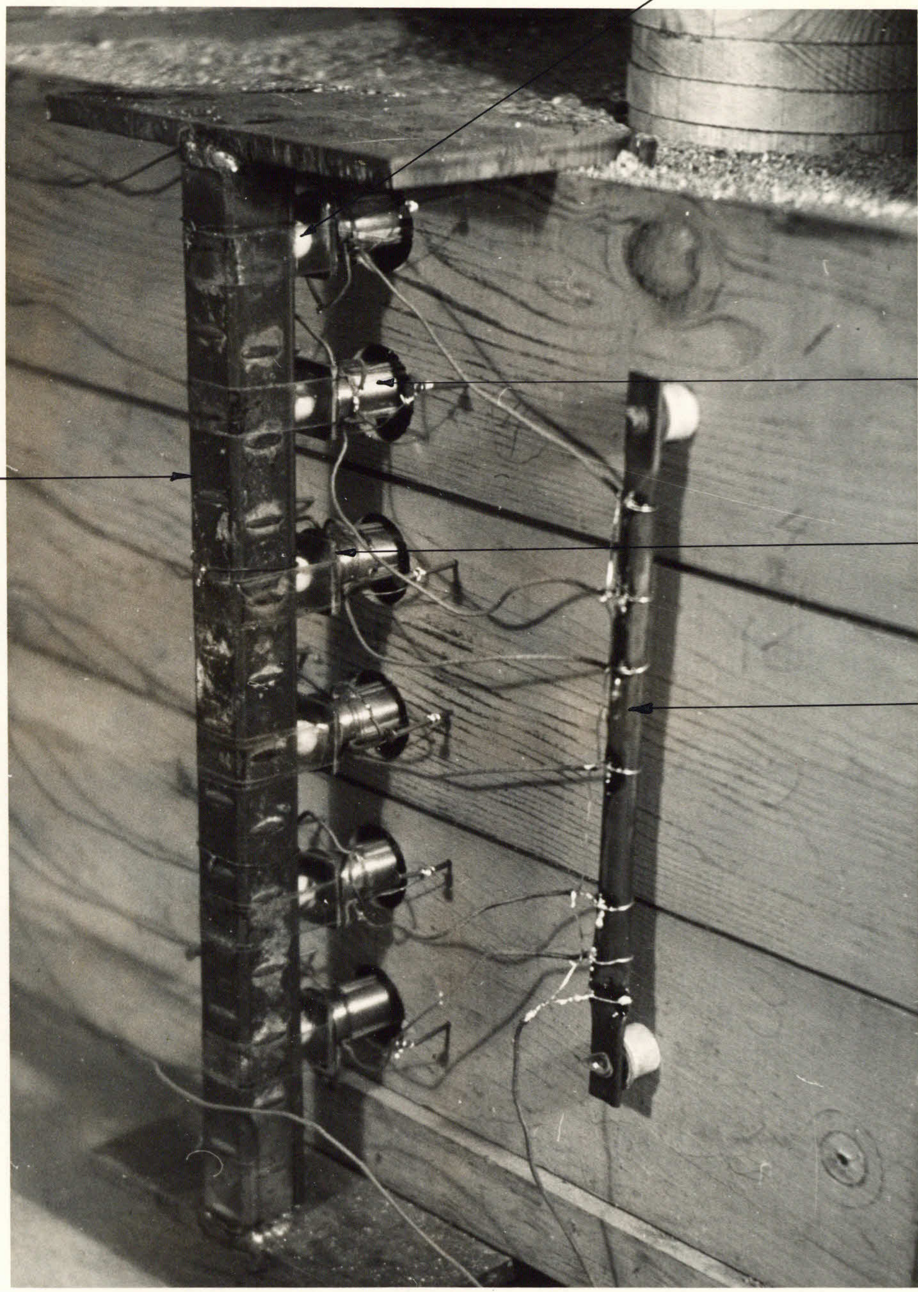

6" I. Beam
1½" x ⅛" Straps
Wood Screws
29"
24"
1¼"
16½"
5@2¾"
Guage Assembly
2x4
2x4
Jack
16 d Spikes
24"
4'-6"
Note: Box made of 2x6's
Guage supports not
shown for clearness
TESTING BOX
DETAIL
Scale: 1"=1'

Figure 6



Gauge Assembly Mounting

① Gauge Assembly
② Shim Plate
③ Marble
④ Support
⑤ Bus Bar

Figure 7

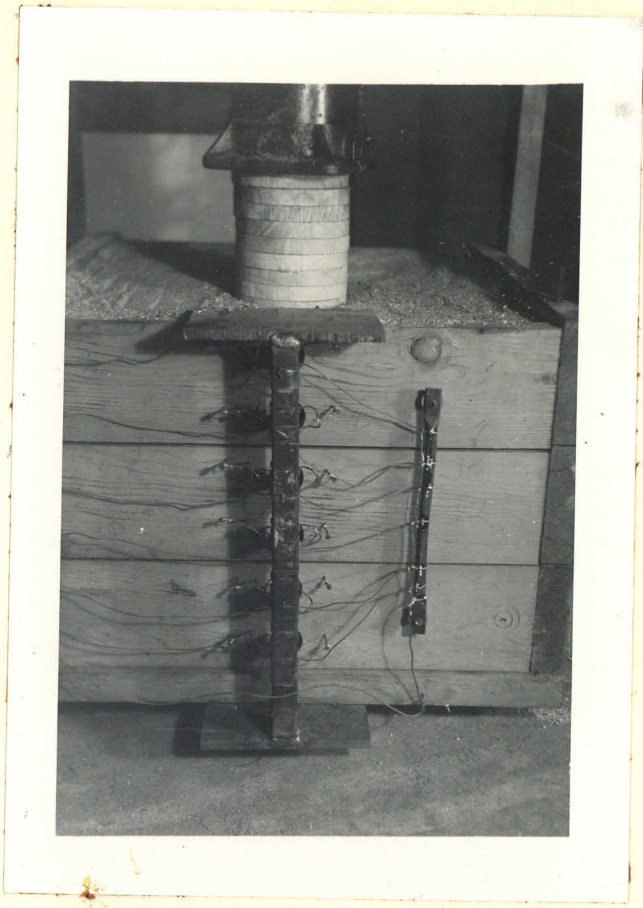


Figure 8

Figure 9

wooden plates to give the right height. A photograph of the loading device is shown in Figure 9. The beam gauge had been previously calibrated; however, as a check it was placed in the 30,000 pound testing machine and loaded with the jack. The original calibration was checked as 0.001 inch deflection = 40 pound load.

The entire test set up is shown in Figure 10.

GAUGE ASSEMBLY CALIBRATION

The calibration of the individual gauge assembly was quite complete and performed with considerable care. The assemblies were first calibrated out of the test box in a 30,000 # Riehle Testing machine. The allowable stress of the brass tube was calculated, and the calibration loads were applied to a maximum considerably below this value. The loads were applied in even increments up to about 800 pounds with readings of the bridge being taken at each point. The load was then removed in even decrements with readings as before. A pronounced hysteresis effect was observed with the first attempt at calibration which led to more investigation of the electrical strain gauge.

Upon consulting with engineers at Vega Aircraft Company who were familiar with the electrical strain gauge, it was learned that this hysteresis effect was not uncommon, and that with proper treatment could be removed or considerably reduced. The application of general heat to the brass tube in sweating on the end plates may have produced internal

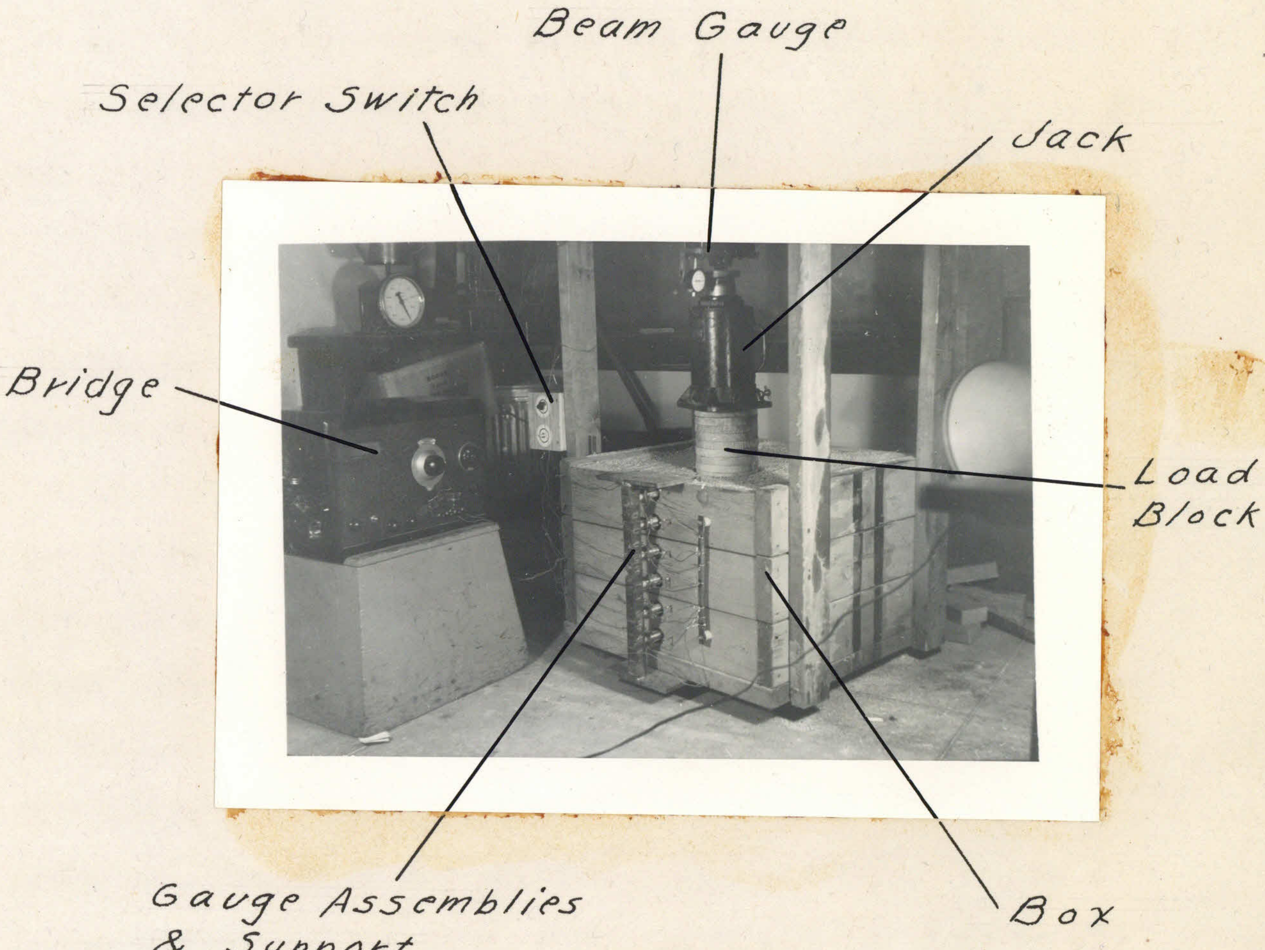

Beam Gauge
Selector Switch
Jack
Bridge
Load Block
Gauge Assemblies & Support
Box

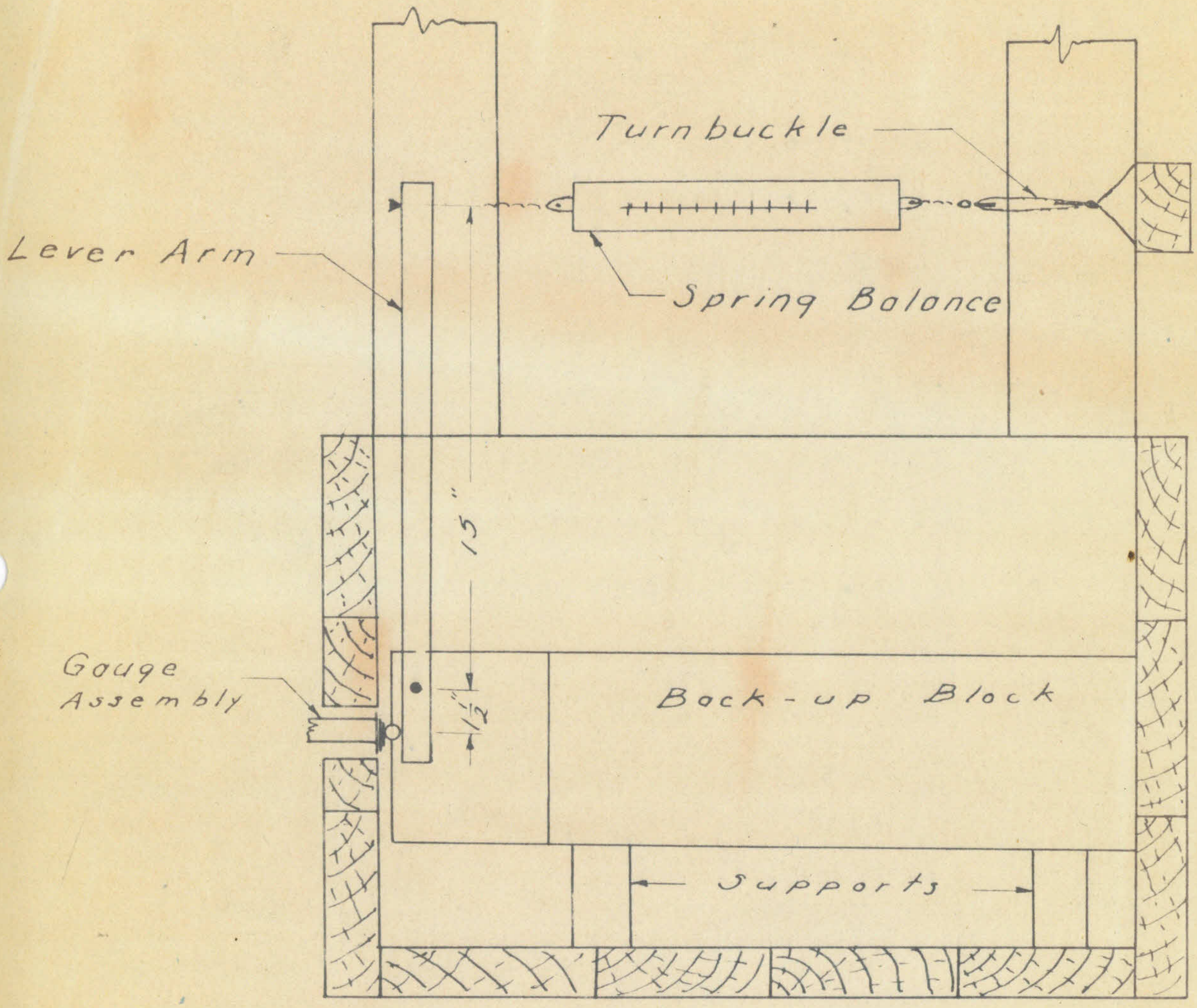
Figure 10

stresses, the removal of which was accomplished by alternately loading and unloading each assembly several times. This apparently removed a good part of the hysteresis effect. Also, the opinion of the men consulted was that the cement used on the gauges would show some slipping until it had set for as long as two weeks. With the realization that our first calibration had been attempted only one week after the application of gauges, it was conjectured that this failure of the cement might have been present.

Allowing for these factors, the testing machine calibration was completed with reliable results. (See calibration curves in Appendix.)

The gauge assemblies were then installed in the test box and were calibrated in place. This "in place" calibration was accomplished by building a simple lever arm device. (See Figure 11). A 50 pound spring balance was used to measure the force on the long arm; and by applying the multiplication factor, the load on the gauge assembly was computed. The load was applied to the assembly through a heavy washer and a marble, thus minimizing any bending effect.

Even increments of loading were applied up to 350 pounds with subsequent decrements to zero. Of course, bridge readings were taken at each point of the loading and unloading cycle. The results of the "in place" calibration agreed substantially with those of the machine calibration. Due to the relative crudeness of the "in place" calibrating device



IN PLACE
CALIBRATION DEVICE
Scale: 2" = 1'0"

Figure 11

the machine calibration was taken as a basis for the first tests. This decision was justified because of the close agreement of the two methods. (See calibration curves in the Appendix.)

TESTS

Before starting the tests, plaster sand was gently placed in the box and was not compacted.

The test technique was as follows: first, a no-load reading of the bridge dial was taken; second, a load was applied with the jack; and third, a bridge dial reading of the loaded gauge assemblies was taken. The no-load reading was taken with the weight of the jack assembly on the sand.

With the gauge equations of the form $L = K(R - Ro)$ and the no-load reading taken with the sand and jack in place, the computed pressures were the extra pressures due to the live area load. A no-load reading had to be taken with each separate test, due to the observed change of gauge assembly resistance. This change was probably because of heating effects.

Because of the fact that extra pressures were measured, negative pressures occasionally resulted. This merely indicates a decrease in the equivalent fluid pressure of the soil.

Trials 1, 2, 3, and 24 (Figure 12)

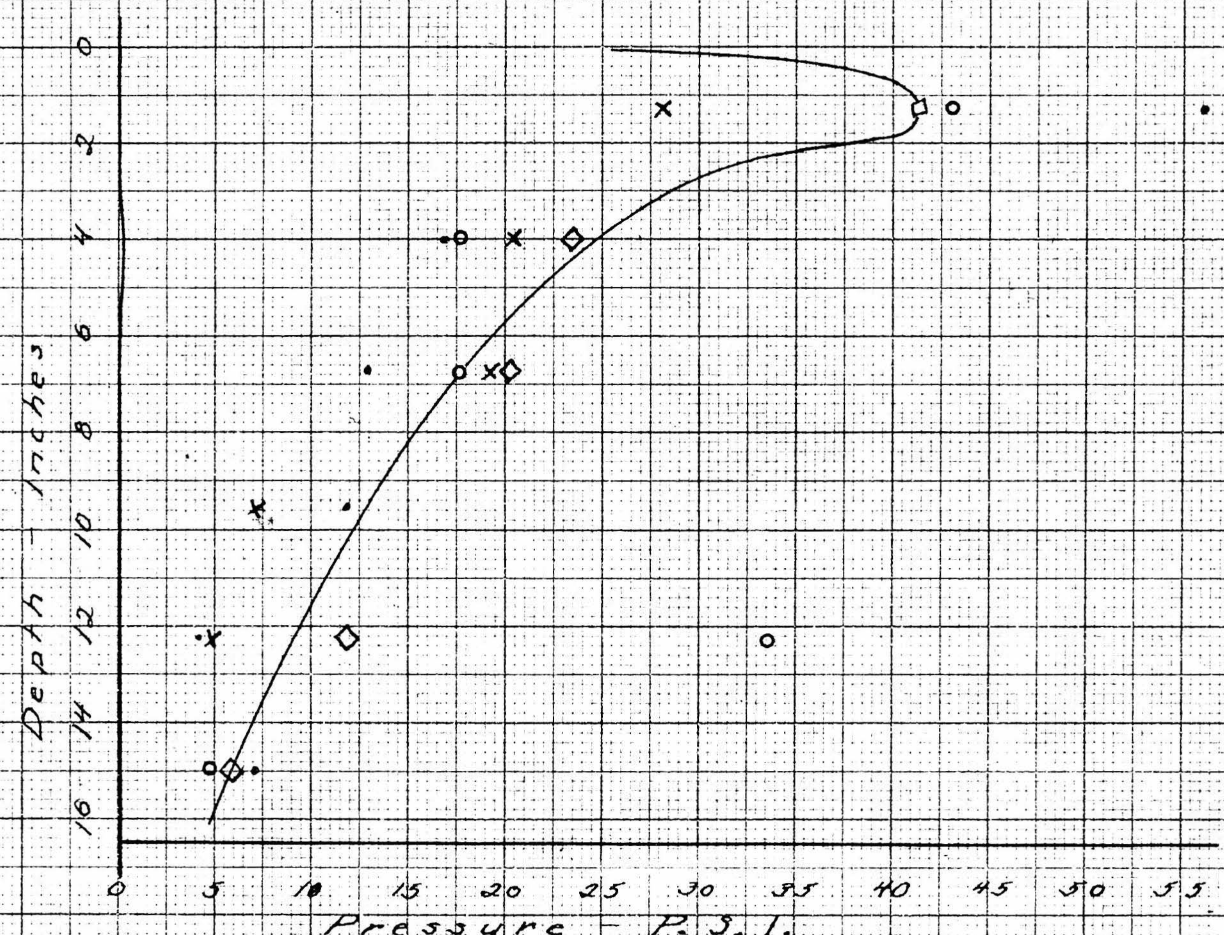
The curves of these trials show the general form of a typical pressure curve. Note the pressure concentration near the top of the box.

Trials 1, 2, 3, and 24 were all run with a 560 pound load on a six inch circular plate with its center eight inches back from the wall face in line with the gauge assemblies.

Trials 1, 2, and 3 were all run with the sand in a fairly undisturbed state. However, it was observed in these three trials that the pressure tended to decrease with the successive trials; that is, the pressures of trial 1 were greater than those of trial 2, which in turn, were greater than those of trial 3. This was probably due to some compaction effect of the sand.

These tests were run in immediate succession. With the application of the load for trial 1, the plate sank about one and one-half inches. No further settlement was observed. In tests 1 and 2 gauge assembly 4 was inoperative; in test 3 gauge assembly 6 did not function.

Trial 24 was run after the sand had been stirred up. The plate sank three-fourths of an inch when loaded. The measured pressures compared well with trials 1, 2, and 3



TRIALS 1,2,3 & 24

Load - 560# on 6" plate

D = 8"

Trial	1	ʘ
	2	⊡
	3	×
	24	·

Figure 12

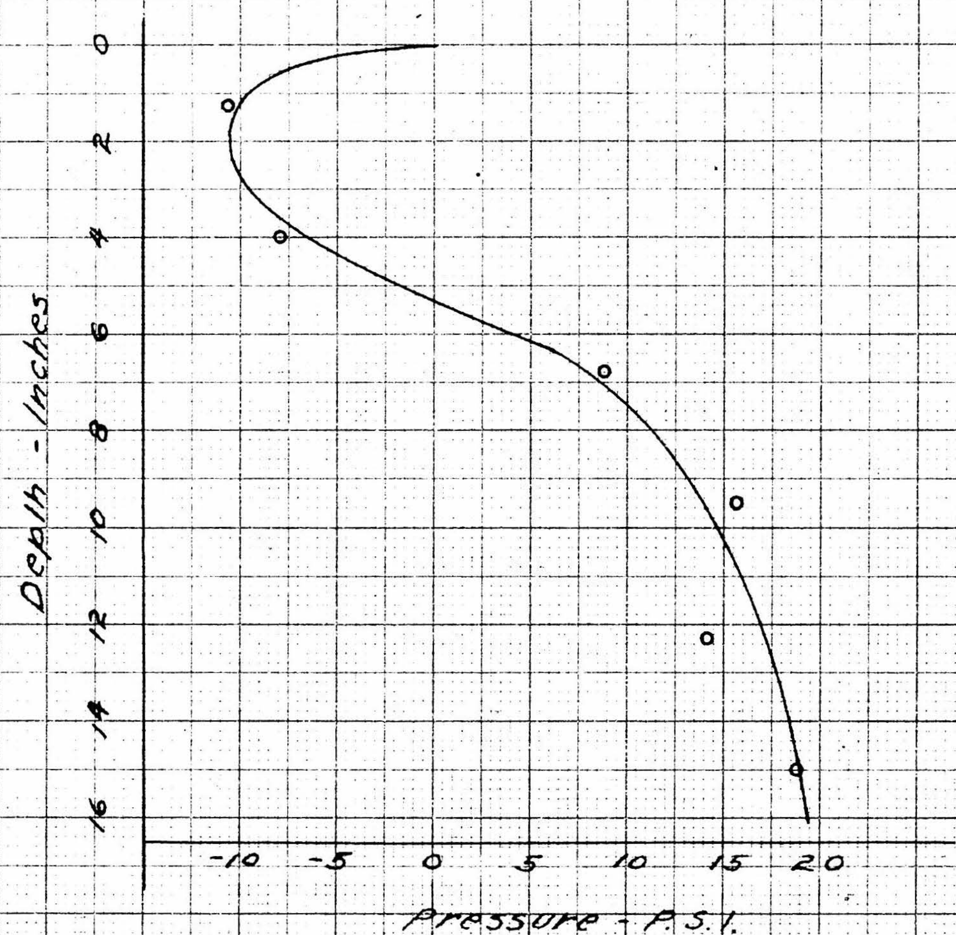
Trial 4 (Figure 13)

This trial shows the effect of soil failure on the pressure distribution. Soil failure is defined as the condition of sustained maximum load and continued settlement.

The plate size and location was similar to trials 1, 2, and 3. The failure load was 680 pounds. This test immediately followed trial 3.

Negative pressures were observed on the two top gauge assemblies, which indicates a decrease in the equivalent fluid pressure of the soil. The highest observed pressures on the three bottom gauge assemblies were recorded on this trial.

One explanation of the pressure distribution (See Figure 13) under failure loads may be this: The load punches its way into the soil and gives a high pressure directly under the load at the bottom of the box. Because of restraint, this pressure is transmitted to the box walls. The decrease of pressure at the top of the wall is caused by a collapse of the soil grains in toward the moving core of soil directly under the load.



TRIAL 4

Failure Load = 680# on 6" plate

D = 8"

Figure 13

Trials 5, 6, 7, and 8 (Figures 14 and 15)

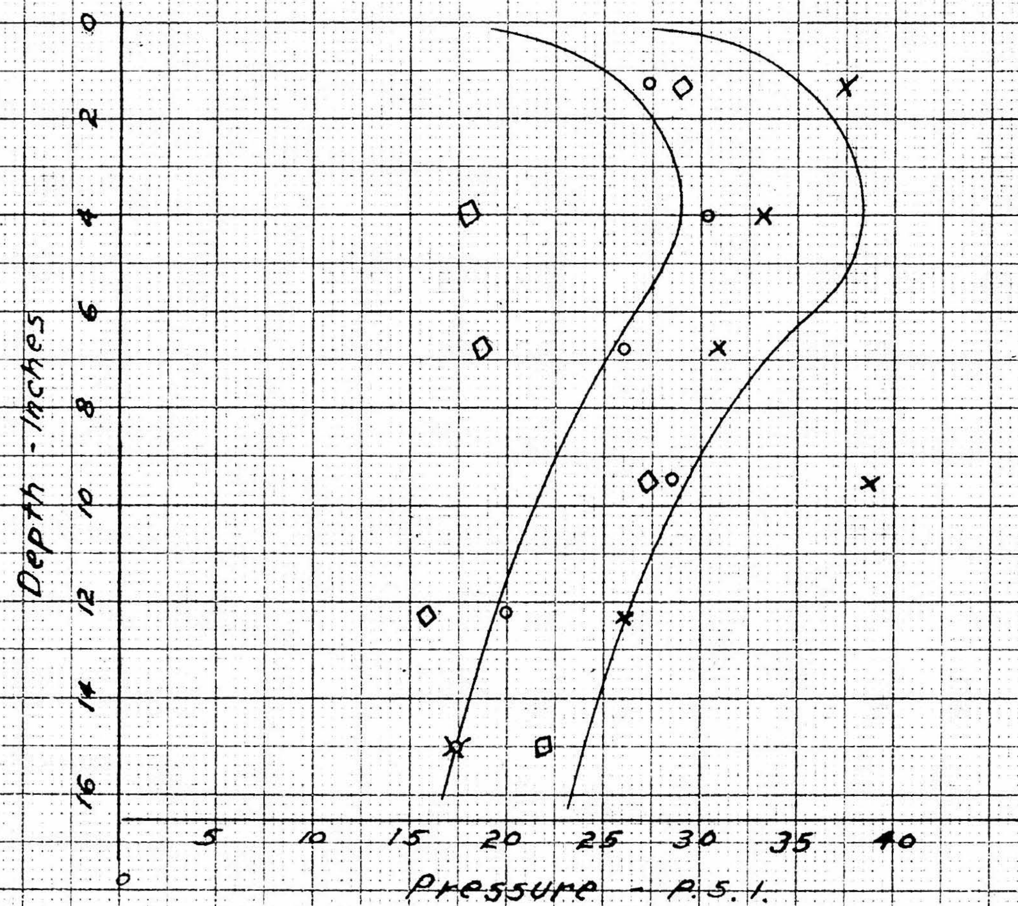
The pressure distribution curves of these tests are shown in Figures 14 and 15.

All tests of this series were run with a ten-inch circular slate with its center 8 inches back from the wall face, in line with the gauge assemblies. Tests 5 and 8 had a 1000 pound load; test 6 had a 1500 pound load; test 7 had a 2000 pound load. No appreciable settlements were observed. These tests immediately followed one another.

Test 6 was computed two ways. Test 6a was computed with the no-load readings of test 6. Test 6b was computed with the no-load readings of test 5. Test 6b may be disregarded.

It was observed that the pressures of tests 5 and 6a were roughly equal. They were plotted as one curve. Test 7, with a greater load than any of this series, shows pressures less than tests 5 and 6, while test 8 shows the lowest pressure of this series. These results confirm the statement of the compaction effect previously noted.

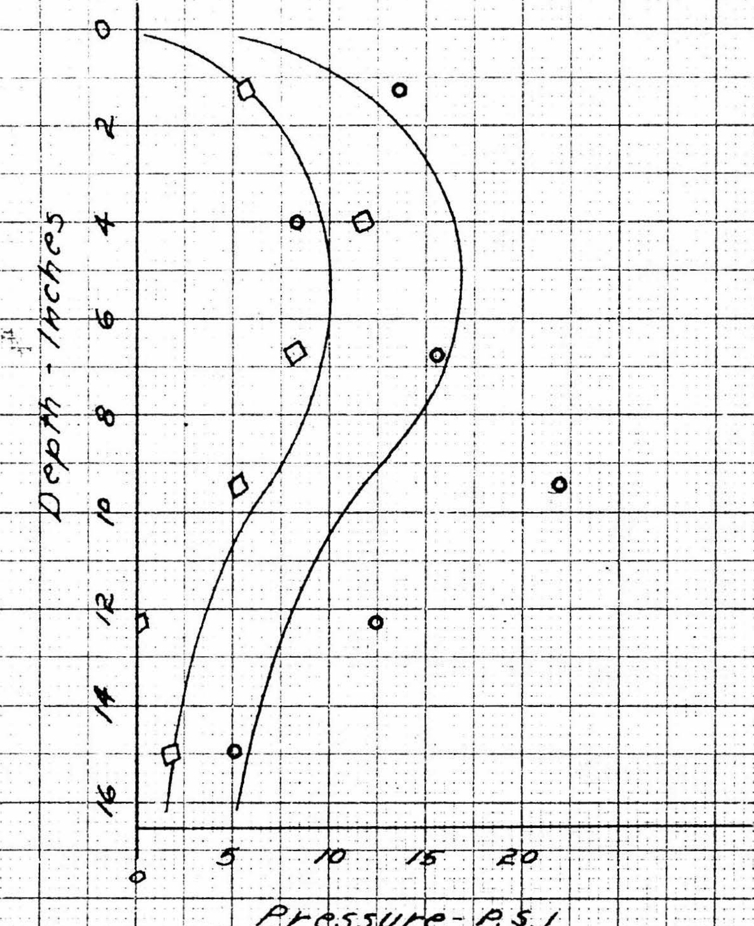
It was observed the pressure on the bottom gauge assembly was greater than the pressure on the one immediately above in trials 6 and 8. This phenomenon was observed in other trials.



TRIALS 5 & 6

Trial 5 - ○ - Load = 1000# on 10" plate
6a - ◇ - Load = 1500# on 10" plate
6b - × - " " " " "
D = 8"

Figure 14



TRIALS 7 & 8

D = 8"

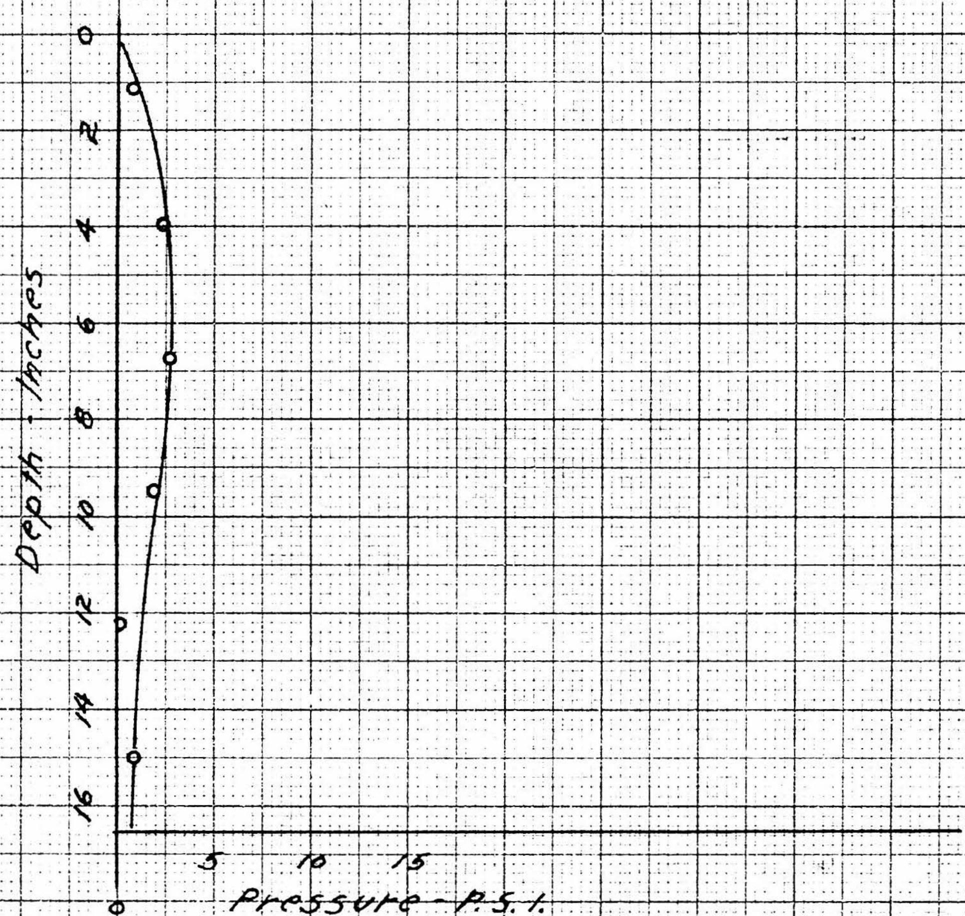
Trial 7 - ○ - Load = 2000# on 10" plate
8 - □ - Load - 1000# on 10" plate

Figure 15

Trial 11 (Figure 16)

This trial was run with a load very near the wall face. A six-inch circular plate with its center 4 inches back from the wall face in line with the gauges assemblys was used. The load was 520 pounds.

The pressure distribution on this test followed the typical form. However, the pressures were smaller than any of the other trials. This trial does not agree with the work of Spangler. The greater pressure on the bottom gauge was observed. No explanation can be offered as to why this test did not give pressures larger than those with the load farther away from the wall.



TRIAL 11

Load = 520# on 6" plate

D = 4"

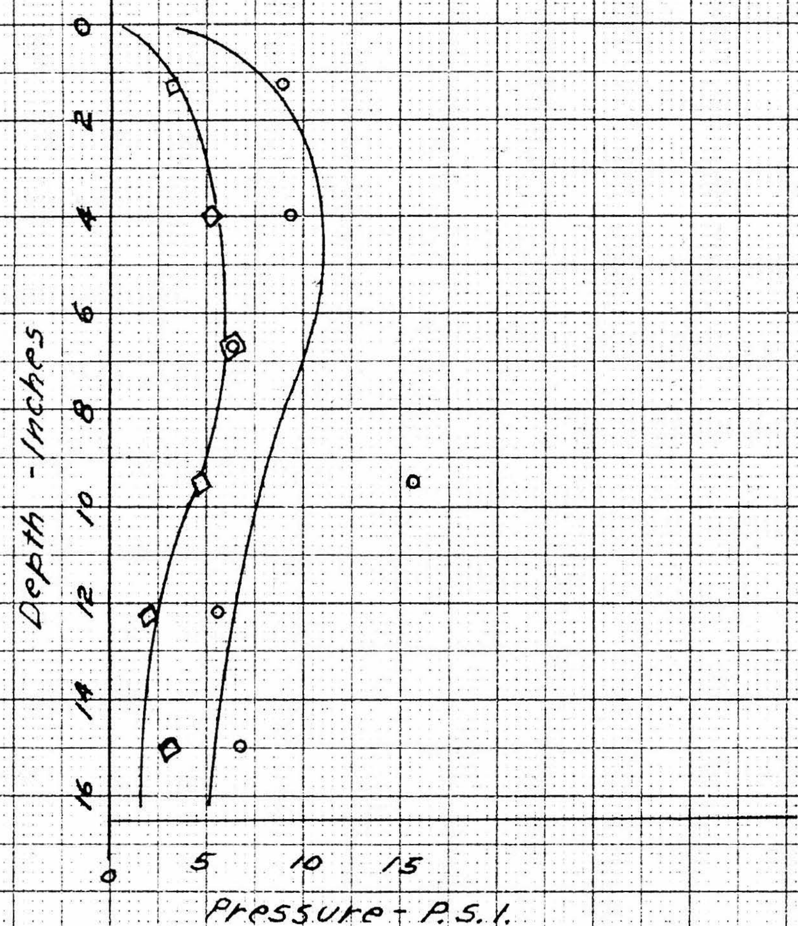
Figure 16

Tests 14 and 15 (Figure 17)

Tests 14 and 15 were performed in the same series; that is, the sand was completely stirred and loosened before test 14 was begun and was not loosened again for test 15. As the figure indicates, test 14 was run with a total load of 560 pounds on a six-inch diameter plate, the center of which was 8 inches from the active face of the wall and in line with the gauge assemblies. With the application of the load, the plate was observed to sink about one inch into the sand. The observed results of test 14 were somewhat lower than was observed in test series one, and the distribution was rather poor. This observed inconsistency may have been due to the erratic nature of the strain gauges; however, the results of test 15 were better.

Test 15 followed 14 immediately. By simply releasing the load of 14 and taking a set of zero readings, 15 was begun. The applied load was again 560 pounds, and the reesults showed a good pressure distribution with magnitudes somewhatnbelow test 14. This phenomenon had been noticed before and was believed to have been caused by a compacting effect in the sand. The apparently proper distribution indicates thatnthe gauges were functioning properly.

These tests show the result that the pressure at the bottom gauge was higher than that at the second gauge from the bottom. This was noticed to be the case generally in all the tests, and this is in agreement with the results obtained by



TRIALS 14 & 15

Load - 560# on 6" plate

D = 8"

Trial 14 ⊙

15 ⊡

Figure 17

Spangler. This higher pressure at the bottom was possibly due to the floor of the box; that is, the floor offered resistance and thus increased the pressure at the bottom.

Trials 17, 18, 19 (Figure 18)

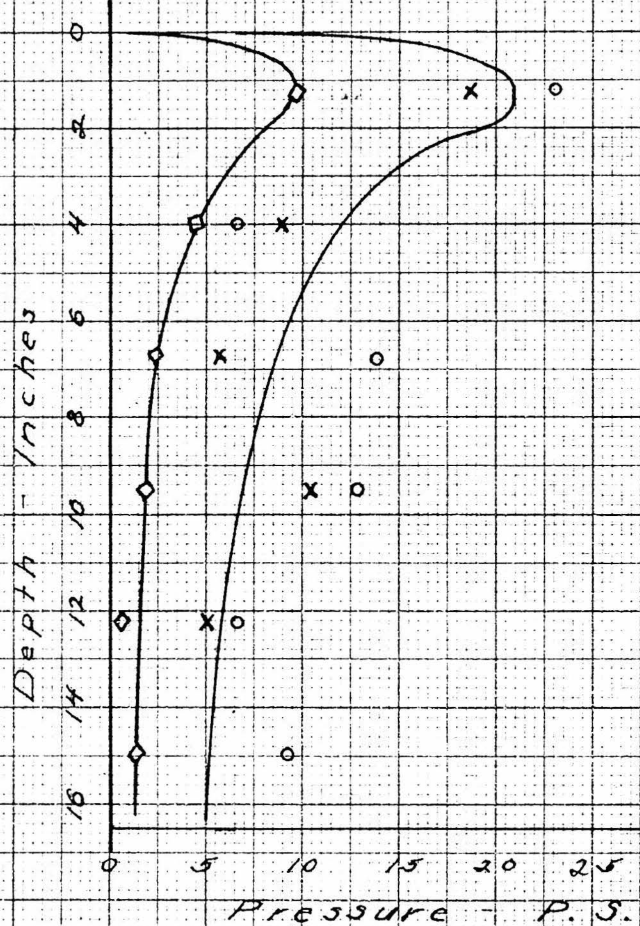
These trials were of the same series as previously discussed. The applied load in each case was 560 pounds, and with the initial application of the load the plate sank about one inch. Plate and location were as in tests 14 and 15. The distribution of pressure was again quite consistent with the magnitude varying considerably.

Test 17 compares quite well in magnitude with test 14 with tests 18 and 19 increasing somewhat. It must be noted that the increase of the pressures after 17 would indicate that the idea of compaction, as previously stated, is in error; however, the decrease was generally the case and tends to verify the statement.

The slight increase in pressure at the bottom gauge was again observed except in test 19. Gauge assembly number 6 was not functioning in test 19.

Trials 20, 21, 22, 23 (Figure 19)

This series was performed with a 6 inch diameter plate and centered 8 inches from the face in line with the gauge assemblies. The applied load was again 560 pounds, and the plate sank three-fourths of an inch. The sand was loosened before test 20, and the test was run in the pre-described



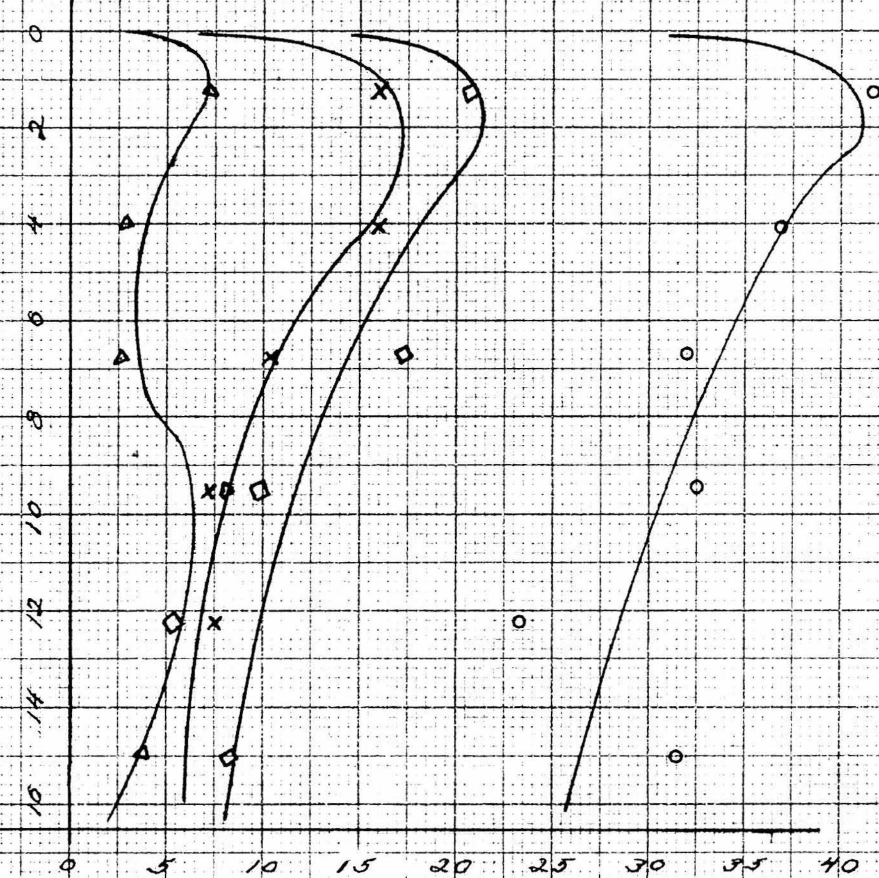
TRIALS 17,18,19

Load - 560# on 6" plate

D = 8"

Trial 17 ◻
18 ⊙
19 X

Figure 18



TRIALS 20,21,22,23

Load - 560# on 6" plate

D = 8"

Trial 20 X
21 ⊙
22 ◻
23 △

Figure 19

manner. The distribution was quite good with the magnitude in accord with trials 18 and 19. After test 20, it was decided to let the equipment stand unloaded for one-half hour before making another test. After this period of time, test 21 was performed with zero readings being taken and the load applied as before. As may be observed in Figure 19, the magnitudes of pressures in test 21 were more than double those of 20. This indicates a definite time effect in the system which may have been due to external temperature. It may have been due to internal temperature; that is, heating within the the electrical circuit, or it may have been due to an actual redistribution of the pressure within the sand. It is apparent that more investigation must be made with respect to this phenomenon.

Tests 22 and 23 were run immediately with results in accord with former trials. The odd shape of the curve for test 23 may have been due to erratic guages or partial failure of the sand.

CONCLUSIONS

The following conclusions are drawn from the data obtained in the research:

1. No exact formula may as yet be given for the horizontal pressure distribution on a retaining wall under a concentered load on the soil surface.

2. The pressures observed on this model were five or ten times greater than the pressures observed in similar

studies on large walls.

3. The use of a small, rigid box for these pressure measurements undoubtedly gives higher pressure because of the restraint of the soil particles. The value of model studies in a soil pressure problem is open to serious questioning.

4. A scale factor could probably be worked out to correlate the observatios on models and full size walls.

5. There is a time-compaction reduction of the pressures. This may be explained as primary lateral distribution of the load through the soil, then as the soil compacts, a secondary distribution of the load downward to the bottom of the box.

6. The pressure at the bottom of the wall tends to be greater than the pressure immediately above the bottom, which was conjectured by Spangler to be due to the bottom of the wall, that is, the floor of the box in this case.

7. Electrical strain gauges afford a convenient and simple method of measuring strains and forces. However, temperature effects may be considerable, as they probably were in this work. It is believed that a gauge assembly with the separate gauges forming the legs of the bridge would smooth out temperature effects.

The results showed good consistency in the distribution of horizontal pressure against the wall but apparently showed little consistency in the magnitude of these pressures.

It is believed that the variation in magnitude was due to heating effects in the strain gauges; however, there may actually have been a redistribution of pressure in the sand. If the effect was one of gauge heating, it may be corrected as suggested by making each side of the bridge an active strain gauge.

Acknowledgement

The authors wish to gratefully acknowledge the assistance and advice recieved from Professor Fredrick J. Converse and Dr. Donald Hudson, of the California Institute of Technology, and from Mr. Walter Hurty, of the Vega Aircraft Company.

Reference

Spangler, M. G., Horizontal Pressures on Retaining Walls Due to Concentrated Surface Loads, Iowa Engineering Experiment Station, Bulletin 140, 1938

Appendix

Principles of Electric Strain Gauges

The elctrical resistance of a wire may be expressed as $R = K\frac{L}{A}$, where R is resistance, L length of wire, A cross-section area, and K a constant.

If we take a wire and compress it (without buckling) the resistance decreases.

Let:

L_0 = Original Length of wire
L = New Length of wire
d_0 = Oringinal Diameter of wire
d = New diameter of wire
ΔL = Change of length
R_0 = Original Resistance
R = New Resistance
μ = Poisson's Ratio
P = Load on Material

$$R_0 = K\frac{L_0}{A} \qquad \left(\text{let } \frac{K}{A} = \frac{c}{d_0^2}\right)$$

$$R_0 = c\frac{L_0}{d_0^2}$$

$$L = L_0 - \Delta L$$

$$d = d_0\left(1 + \mu\frac{\Delta L}{L_0}\right)$$

$$R = \frac{c(L_0 - \Delta L)}{d_0^2\left(1 + \mu\frac{\Delta L}{L_0}\right)^2} = \frac{c(L_0 - \Delta L)}{d_0^2\left(1 + 2\mu\frac{\Delta L}{L_0} + \mu^2\frac{\Delta L^2}{L_0^2}\right)}$$

Letting $\frac{c}{d_0^2} = c'$ and neglecting small terms

$$R = c'(L_0 - \Delta L)\left(1 - 2\mu\frac{\Delta L}{L_0}\right)$$

$$R = c'\left(L_0 - 2\mu\Delta L - \Delta L + 2\mu\frac{\Delta L}{L_0}\right)$$

neglecting small terms

$$R = c'[L_0 - \Delta L(1 + 2\mu)]$$

but:

$$\Delta L = K_1 P$$

$$R = c'[L_0 - K_1 P(1 + 2\mu)]$$

let

$$K_1(1 + 2\mu) = K_2$$

$$R = c'[L_0 - K_2 P]$$

$$P = \frac{L_0}{K_2} - \frac{R}{c'K_2}$$

but

$$L_0 = \frac{R_0}{c'}$$

$$P = \frac{1}{K_2 c'}(R_0 - R)$$

let

$$\frac{1}{K_2 c'} = K$$

$$P = K(R_0 - R)$$

Because of our wiring sett up this goes to:

$$P = K(R - R_0)$$

To utilize this principle of resistance change in measuring strains several very fine wires are cemented between tissue paper sheets which in turn are cemented to the surface on which strains are to be measured.

As derived the resistance varies linearly with strain; however, it is generally recognized that there are unknown factors that slightly disturb this linear relation. The technique of cementing is very important; faulty technique will ruin the gauge. Also there is a hysteresis effect in the cement itself.

In spite of these difficulties, electrical strain gauges afford a very convenient means of measuring strains or forces in metals.

CALIBRATION EQUATIONS

Gauge Assembly #1

$$\frac{L}{R - R_0} = \frac{800}{190.5 - 93.8} = \frac{800}{96.7} = 8.27$$

$$L_1 = 8.27 (R - R_0)$$

Gauge Assembly #2

$$\frac{L}{R - R_0} = \frac{800}{206.2 - 93.0} = \frac{800}{113.2} = 7.06$$

$$L_2 = 7.06 (R - R_0)$$

Gauge Assembly #3

$$\frac{L}{R - R_0} = \frac{800}{196.3 - 92.5} = \frac{800}{103.8} = 7.60$$

$$L_3 = 7.60 (R - R_0)$$

Gauge Assembly #4

$$\frac{L}{R - R_0} = \frac{790}{185.5 - 91.0} = \frac{790}{94.5} = 8.36$$

$$L_4 = 8.36 (R - R_0)$$

Gauge Assembly #5

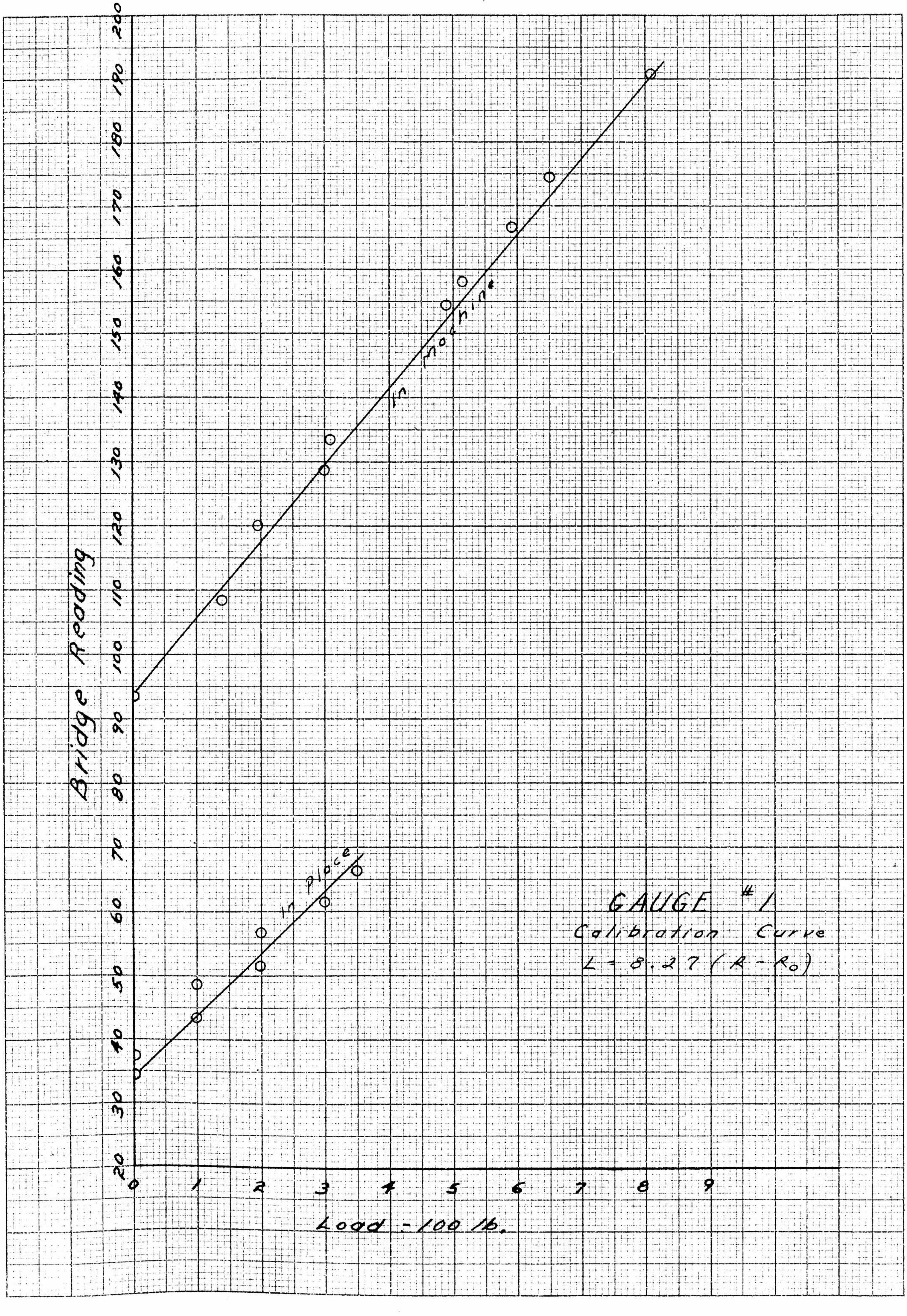
$$\frac{L}{R - R_0} = \frac{800}{183.8 - 75.0} = \frac{800}{108.8} = 7.35$$

$$L_5 = 7.35 (R - R_0)$$

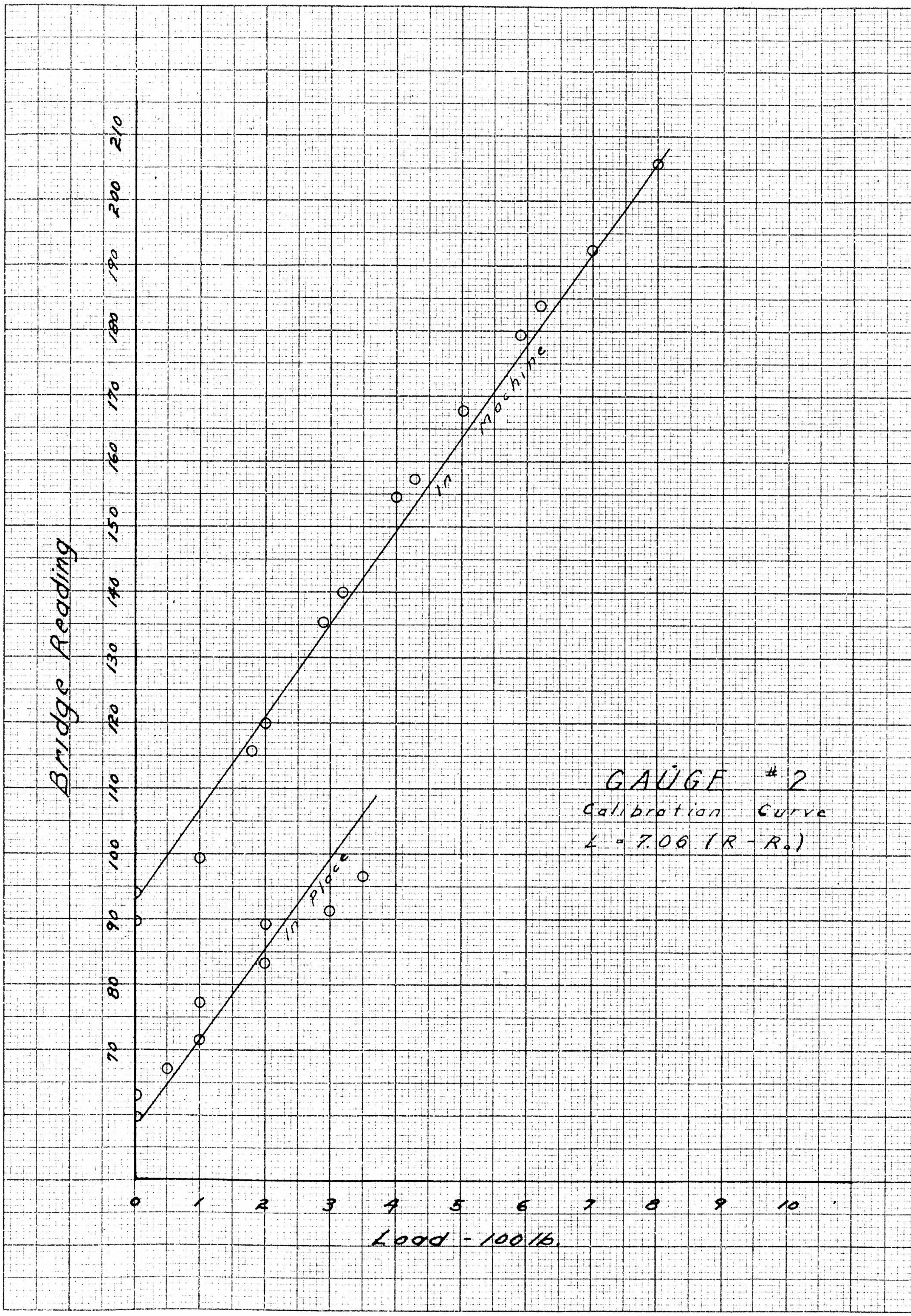
Gauge Assembly #6

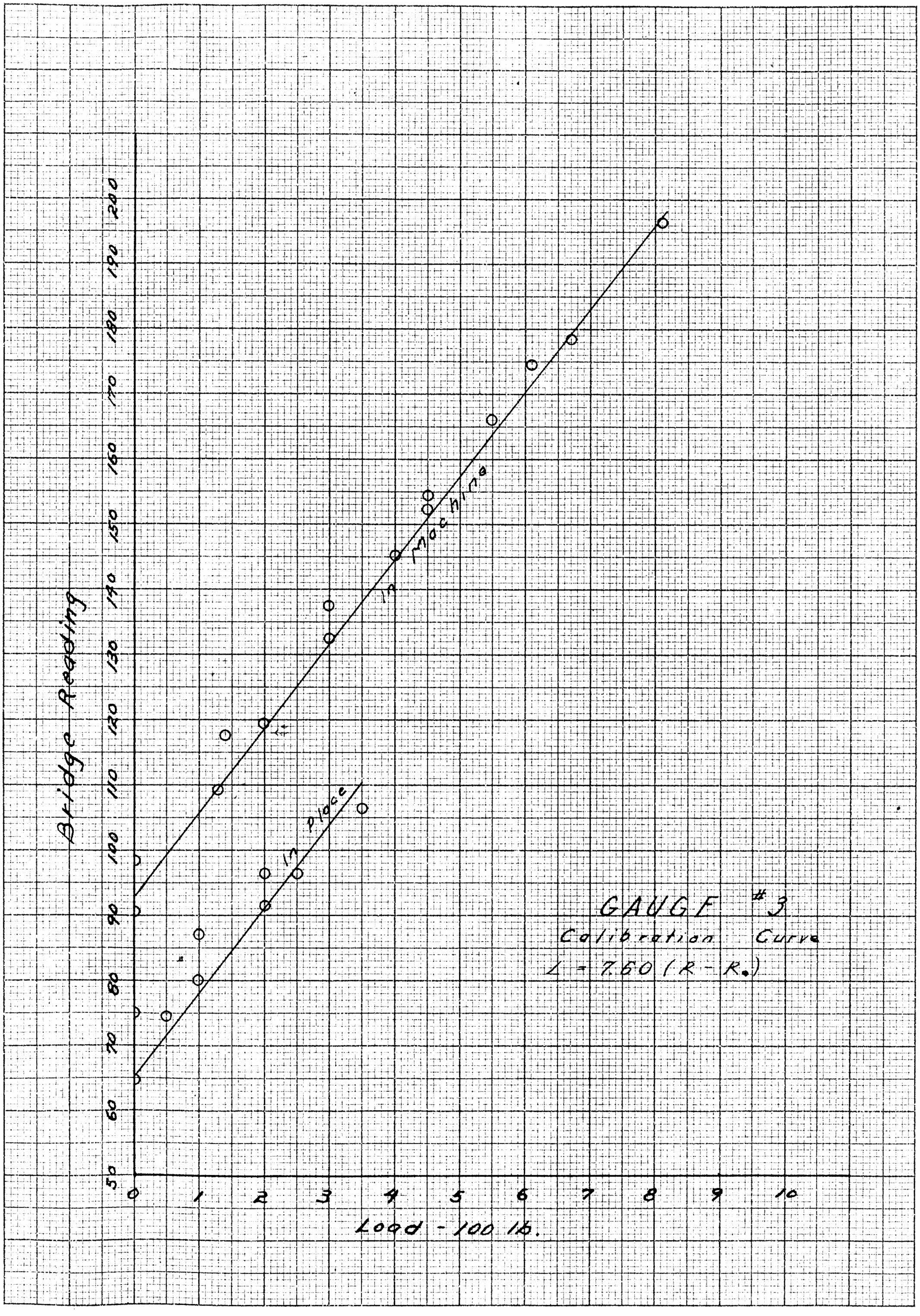
$$\frac{L}{R - R_0} = \frac{810}{115.8 - 16.0} = \frac{810}{99.8} = 8.12$$

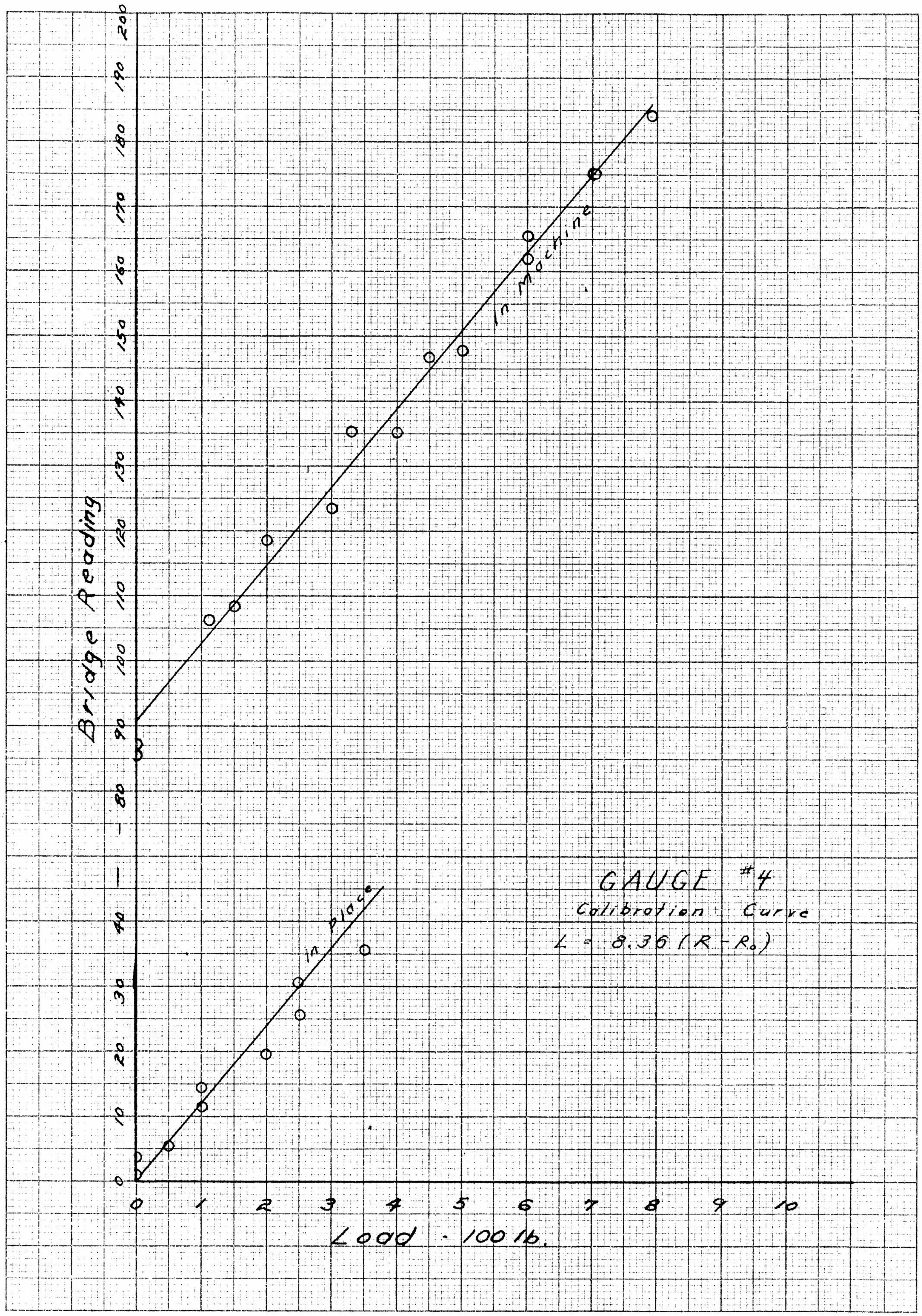
$$L_6 = 8.12 (R - R_0)$$

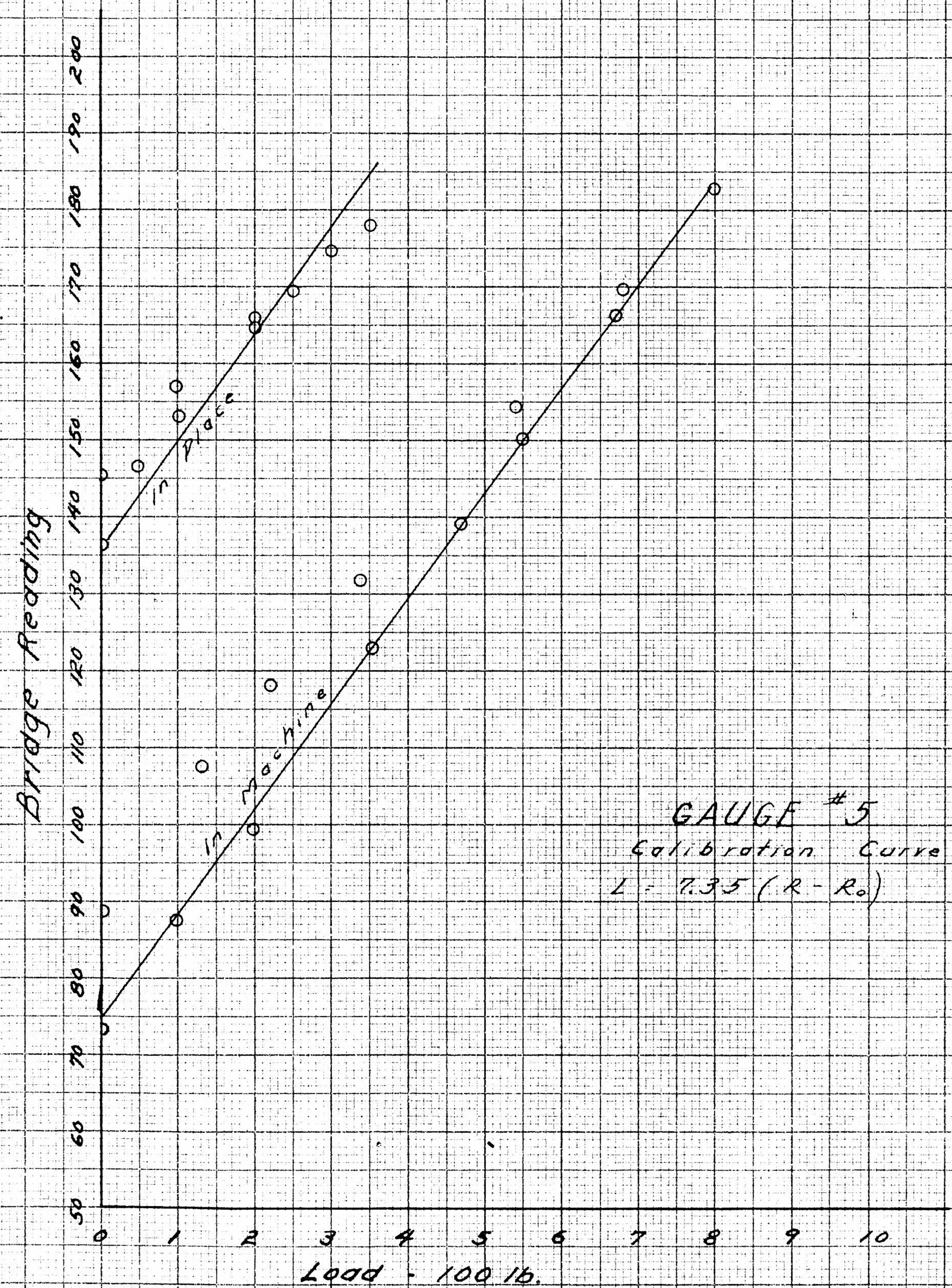


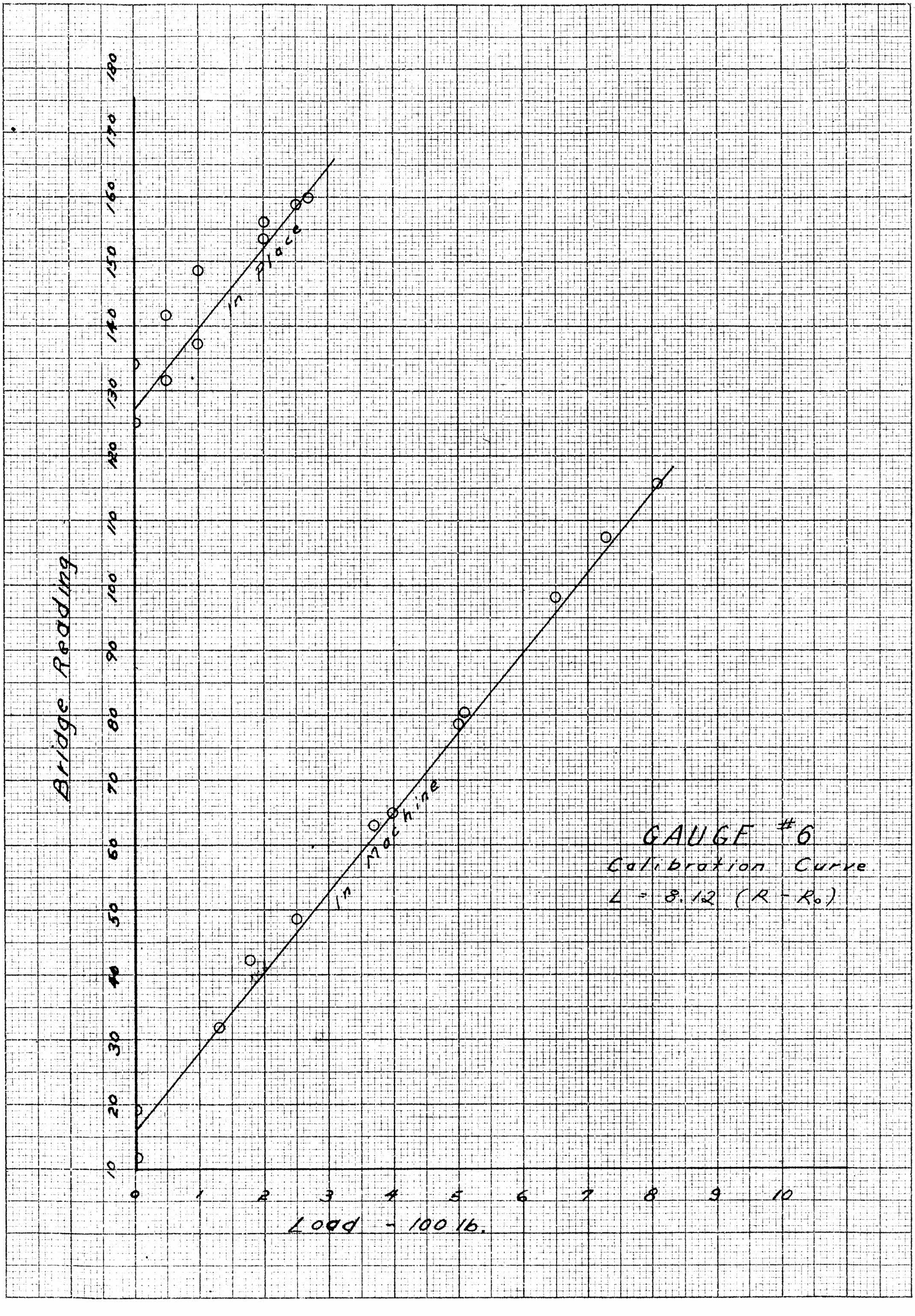
Bridge Reading
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
0
1
2
3
4
5
6
7
8
9
Load - 100 lb.
In machine
In place
GAUGE # 1
Calibration Curve
L = 8.27 (R - Ro)


Bridge Reading
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
0
1
2
3
4
5
6
7
8
9
10
Load - 100 lb.
In Machine
In Place
GAUGE # 2
Calibration Curve
L = 7.06 (R - R₀)


Bridge Reading
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
0 1 2 3 4 5 6 7 8 9 10
Load - 100 lb.
In machine
In place
GAUGE #3
Calibration Curve
L = 7.60 (R - R₀)


GAUGE #4
Calibration Curve
L = 8.36 (R - R₀)
In Machine
In place
Bridge Reading
Load - 100 lb.
0
10
20
30
40
80
90
100
110
120
130
140
150
160
170
180
190
200
0
1
2
3
4
5
6
7
8
9
10


Bridge Reading
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
0
1
2
3
4
5
6
7
8
9
10
Load - 100 lb.
In Place
In Machine
GAUGE #5
Calibration Curve
L - 7.35 (R - Ro)



Bridge Reading
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
0
1
2
3
4
5
6
7
8
9
10
Load - 100 lb.
In Place
In Machine
GAUGE #6
Calibration Curve
L = 8.12 (R - R₀)

TEST DATA

Trial #1 D 8" Load sank 1-1/2" Jan. 22, 1944

Load: Beam Gauge	Load: lbs.	Gauge No.	Depth	R	R	R-R	K	F	P
14	560	1	1-1/4"	2-75.5	2-66.3	9.2	8.27	76.0	42.9
		2	4"	2-100.2	2-95.8	4.4	7.06	31.1	17.6
		3	6-3/4"	2-108.2	2-104.1	4.1	7.60	31.2	17.6
		4	9-1/2"	-	-	-	8.36	-	-
		5	12-1/4	3-39.0	3-30.9	8.1	7.35	59.5	33.6
		6	15"	1-100	1-99.0	1.0	8.12	8.1	4.6

Trial #2 D 8" Jan. 22

14	560	1	*	2-79.1	2-70.3	8.8	*	72.9	41.2
		2	*	2-105.6	2-99.7	5.9	*	41.5	23.5
		3	*	2-113.9	2-109.2	4.7	*	35.8	20.2
		4	*	-	-	-	*	-	-
		5	*	3-41.5	3-38.6	2.9	*	21.3	12.0
		6	*	1-61.0	1-59.7	1.3	*	10.5	6.0

Trial #3 D 8" Jan. 22

14	560	1	*	2-77.8	2-71.8	6.0	*	49.6	28.0
		2	*	2-106.3	2-101.2	5.1	*	36.0	20.3
		3	*	2-105.7	101.1	4.6	*	35.0	19.2
		4	*	3-40.0	3-38.5	1.5	*	12.5	7.1
		5	*	3-40.4	3-39.2	1.2	*	8.7	4.9
		6	*	1-56.2	57.6	-1.4	? -	-	-

Trial #4 D 8" Soil Failure Jan. 22 Sank 1-1/2"

17	680	1	*	2-77.5	2- 79.8	-2.3	*	-19.0	-10.7
		2	*	2-106	2- 108	-2.0	*	-8.0	- 8.0
		3	*	2-116.5	2-114.4	2.1	*	16.0	9.0
		4	*	2-42.0	2-38.7	3.3	*	27.6	15.6
		5	*	3-42.4	3-39.2	3.4	*	25.0	14.1
		6	*	3-129	3-124.9	4.1	*	33.3	18.8

Trial #5 D 8" 10" plate Jan. 22

25	1000	1	*	2-78.2	2-72.3	5.9	*	48.1	27.2
		2	*	2-107.8	2-100.2	7.6	*	53.6	30.3
		3	*	2-116.8	2-111.0	5.8	*	44.1	25.9
		4	*	2-42.8	2-36.8	6.0	*	50.1	28.3
		5	*	3-43.3	3-38.5	4.8	*	35.3	19.9
		6	*	2-62.0	2-58.2	3.8	*	30.8	17.4

TEST DATA

Trial #6 D 8" Jan. 22

Load: Beam Gauge	Load: lbs.	Gauge No.	Depth	R	R_o	$R-R_o$	K	F lbs.	P psi.	
37.5	1500	1	*	2-80.3	2-74.1	6.2	*	51.4	29.0	
		2	*	2-108.5	2-104.0	4.5	*	31.8	18.0	
		3	*	2-118.2	2-113.8	4.4	*	33.2	18.7	6a
		4	*	2-45.0	2-39.2	5.8	*	48.5	27.4	
		5	*	3-44.8	3-41.0	3.8	*	27.9	15.8	
		6	*	2-60.0	2-55.2	4.8	*	39.0	22.0	
						8.0	*	66.1	37.4	
						8.3	*	58.6	33.1	
						7.2	*	54.7	30.9	6b
						8.2	*	68.6	38.8	
						6.3	*	46.3	26.2	
						3.8	*	30.8	17.4	

Trial #7 D 8" 10" Plate Load sank 3/4" Jan. 22

50	2000	1	*	2-81.2	2-78.3	2.9	*	24.0	13.6
		2	*	2-109.3	2-107.2	2.1	*	14.8	8.4
		3	*	2-120.2	2-116.6	3.6	*	27.4	15.5
		4	*	2-46.9	2-42.3	4.6	*	38.5	21.8
		5	*	3-46.5	3-43.5	3.0	*	22.0	12.4
		6	*	2-104.0	2-102.9	1.1	*	8.9	5.0

Trial #8 D 8" 10" Plate Jan. 22

25	1000	1	*	2-76.8	2-75.5	1.2	*	9.9	5.6
		2	*	2-106.7	2-103.7	3.0	*	21.1	11.9
		3	*	2-115.6	2-113.7	1.9	*	14.4	8.1
		4	*	2-40.0	2-38.9	1.1	*	9.2	5.2
		5	*	3-40.0	3-40.0	0.0	*	0.0	0.0
		6	*	2-96.0	2-95.6	0.4	*	3.3	1.8

Trial #11 D 4" 6" Plate Jan. 22

13	520	1	*	2-77.6	2-77.5	0.1	*	0.85	0.47
		2	*	2-104.2	2-104.8	-	*	-	-
		3	*	2-113.8	2-113.2	0.6	*	4.56	2.58
		4	*	2-39.2	2-38.4	0.4	*	3.34	1.89
		5	*	3-38.8	3-38.8	0.0	*	0.0	0.0
		66	*	3-29.2	3-29.0	0.2	*	1.62	0.91

TEST DATA

Before Trial #14 - Sand loosened

Trial #14   D 8"   6" Plate   Jan. 22

Load Beam Gauge	Load lbs.	Gauge No.	Depth	R	R	R - R	K	F lbs.	p psi.
14	560	1	*	2-85.4	2-83.5	1.9	*	15.7	8.9
		2	*	2-113.1	2-110.8	2.3	*	16.3	9.2
		3	*	2-121.8	2-120.3	1.5	*	11.4	6.4
		4	*	2-51.0	2-47.9	3.1	*	25.9	14.6
		5	*	3-48.2	3-46.7	1.3	*	9.6	5.4
		6	*	3-36.4	3-34.9	1.5	*	12.2	6.9

Trial #15   D 8"   6" Plate   Load sank 1"   Jan. 22

Load Beam Gauge	Load lbs.	Gauge No.	Depth	R	R	R - R	K	F lbs.	p psi.
14	560	1	*	2-85.6	2-84.9	0.7	*	5.8	3.3
		2	*	2-112.9	2-111.6	1.3	*	9.2	5.2
		3	*	2-122.1	2-120.6	1.5	*	11.4	6.4
		4	*	2-51.1	2-50.1	1.0	*	8.4	4.7
		5	*	3-49.0	3-48.5	0.5	*	3.7	2.1
		6	*	3-36.4	3-35.7	0.7	*	5.7	3.2

Trial #16   D 8"   6" Plate   Jan. 22

Load Beam Gauge	Load lbs.	Gauge No.	Depth	R	R	R - R	K	F lbs.	p psi.
14	560	1	*	2-74.5	2-80.3	-	*	-	-
		2	*	2-103.7	2-107.0	-	*	-	-
		3	*	2-113.2	2-117.1	-	*	-	-
		4	*	2-4016	2-44.9	-	*	-	-
		5	*	3-36.3	3-42.5	-	*	-	-
		6	*	3-24.2	3-30.0	-	*	-	-

Before Trial #17 - Sand loosened

Trial #17   D 8"   6" Plate   Load sank 3/4"   Jan. 25

Load Beam Gauge	Load lbs.	Gauge No.	Depth	R	R	R - R	K	F lbs.	p psi.
14	560	1	*	2-57.3	2-55.2	2.1	*	17.4	9.8
		2	*	2-84.0	2-82.9	1.1	*	7.8	4.4
		3	*	2-92.3	2-91.8	0.5	*	3.8	2.2
		4	*	2-22.3	2-21.9	0.4	*	3.3	1.9
		5	*	3-19.8	3-19.7	0.1	*	0.7	0.4
		6	*	3-07.4	3-07.1	0.3	*	2.4	1.4

Trial #18   D 8"   6" Plate

Load Beam Gauge	Load lbs.	Gauge No.	Depth	R	R	R - R	K	F lbs.	p psi.
14	560	1	*	2-56.5	2-51.6	4.9	*	40.6	23.0
		2	*	2-81.9	2-80.3	1.6	*	11.3	6.4
		3	*	2-93.1	2-89.9	3.2	*	24.3	13.8
		4	*	2-21.9	2-19.2	2.7	*	22.6	12.8
		5	*	3-18.7	2-17.1	1.6	*	11.7	6.6
		6	*	3-07.0	3-05.0	2.0	*	16.2	9.2

TEST DATA

Trial. #19 D 8" 6" Plate Jan. 25

Load Beam Gauge	Load lbs.	Gauge No.	Depth De	R	R_{oo}	$R - R_o$	K	F lbs.	P psi.
14	560	1	*	2-59.5	2-55.5	4.0	*	33.1	18.7
		2	*	2-85.1	2-82.9	2.2	*	15.6	8.8
		3	*	2-94.3	2-93.0	1.3	*	9.9	5.6
		4	*	2-24.7	2-22.5	2.2	*	18.4	10.4
		5	*	3-21.0	3-19.8	1.2	*	8.8	5.0
		6	*	3-08.4	3-08.0	0.4	*	3.2	1.8

Trial #20 D 8" 6" Plate Sand Loosened, Load sank 3/4" Jan. 25

14	560	1	*	2-60.6	2-57.2	3.4	*	28.1	15.9
		2	*	2-87.4	2-83.4	4.0	*	28.2	15.9
		3	*	2-96.0	2-93.6	2.4	*	18.3	10.4
		4	*	2-25.0	2-23.5	1.5	*	12.5	7.1
		5	*	3-19.4	3-17.6	1.8	*	13.2	7.5
		6	*	2-157.7	2-151.2	-	*	-	-

Half hour elapsed between 20 and 21

Trail # 21 D 8" 6" Plate Jan 25.

14	560	1	*	2-62.4	2-53.5	8.9	*	73.6	41.6
		2	*	2-90.0	2-80.9	9.1	*	65.2	36.8
		3	*	2-99.7	2-92.3	7.4	*	56.2	31.8
		4	*	2-28.8	2-21.9	6.9	*	57.7	32.6
		5	*	3-25.7	3-20.1	5.6	*	41.2	23.3
		6	*	3-15.6	3-08.7	6.9	*	55.9	31.5

Trial #22 D 8" 6" Plate Jan. 25

14	560	1	*	2-63.8	2-59.4	4.4	*	36.4	20.6
		2	*	2-90.9	2-86.9	4.0	*	28.2	15.9
		3	*	2-100.3	2-96.3	4.0	*	30.4	17.2
		4	*	2-28.0	2-25.9	2.1	*	17.6	9.9
		5	*	3-25.0	3-23.7	1.3	*	9.60	5.4
		6	*	3-13.8	3-12.0	1.8	*	14.6	8.2

TEST DATA

Trial # 23 D 8" 6" Plate Load sank 1" Jan. 25

Load: Beam Gauge	Load: lbs.	Gauge No.	Depth	R	R_o	$R - R_o$	K	F	P
20	800	1	*	2-62.1	2-60.6	1.5	*	12.4	7.0
		2	*	2-90.1	2-89.4	0.7	*	4.9	2.8
		3	*	2-100.2	2-99.6	0.6	*	4.6	2.6
		4	*	2-30.4	2-28.7	1.7	*	14.2	8.0
		5	*	3-24.7	3-26.3	1.4	*	10.3	5.8
		6	*	3-14.1	3-14.9	-0.8	*	-6.5	-3.7

Sand loosened before Trial # 24

Trial # 24 D 8" 6" Plate Jan. 25

14	560	1	*	2-62.6	2-50.6	12.0	*	99.2	56.0
		2	*	2-90.2	2-85.9	4.3	*	30.4	17.1
		3	*	2-99.6	2-96.6	3.0	*	22.8	12.9
		4	*	2-29.4	2-26.9	2.5	*	20.9	11.8
		5	*	3-25.5	3-24.4	1.1	*	8.1	4.6
		6	*	3-14.3	3-12.8	1.5	*	12.2	7.0

MACHINE CALIBRATION TESTS

Gauge Assembly #1

Load (lbs.)	Bridge Dial
0	4 - 93.7
195	120.0
310	133.5
490	154.8
490	5 - 8.0
650	27.5
810	44.0
590	20.0
515	11.2
515	4 - 158.2
300	128.8
140	108.5
0	93.0

Gauge Assembly #2

Load (lbs.)	Bridge Dial
0	2 - 89.8
100	99.5
200	120.0
320	140.0
430	157.4
430	3 - 9.1
590	30.0
700	44.0
800	57.5
620	35.5
500	19.5
400	7.9
400	2 - 153.4
290	135.2
130	115.3
0	94.0

Gauge Assembly #3

Load (lbs.)	Bridge Dial
0	3 - 90.6
130	109.3
200	119.5
300	132.3
400	145.2
450	152.6
450	4 - 5.9
550	19.5
670	31.5
810	50.0
610	28.0
450	7.5
450	3 - 154.7
300	137.8
140	117.5
0	98.5

Gauge Assembly #4

Load (lbs.)	Bridge Dial
0	4 - 87.2
110	106.5
200	118.7
330	135.3
450	146.8
450	5 - 0.0
600	18.6
705	28.3
790	37.3
700	28.4
600	15.0
500	1.6
500	4 - 147.1
400	135.2
300	123.0
150	108.2
0	85.4

MACHINE CALIBRATION TESTS

Gauge Assembly #5

Load (lbs.)	Bridge Dial
0	3 - 73.2
100	87.9
200	100.0
355	123.0
470	139.4
550	150.1
550	4 - 3.8
670	20.4
800	36.3
680	23.2
540	8.2
540	3 - 155.4
340	131.8
220	118.0
130	107.5
0	89.7

Gauge Assembly #6

Load (lbs.	Bridge Dial
0	3 - 11.6
130	32.0
250	48.8
400	65.1
500	78.9
730	107.9
810	115.8
650	98.2
510	80.3
370	63.0
180	42.6
0	19.1

IN PLACE CALIBRATION TESTS

Gauge Assembly #1

Load (lbs.)	Bridge Dial
0	2 - 34.7
100	43.6
200	51.2
300	61.8
350	66.3
200	56.8
100	48.4
0	37.2

Gauge Assembly #2

Load (lbs.)	Bridge Dial
0	2 - 59.5
50	67.1
100	71.7
200	83.2
300	91.2
350	96.5
200	89.3
100	77.3
0	62.8

Gauge Assembly #3

Load (lbs.)	Bridge Dial
0	2 - 64.7
50	74.9
100	80.0
200	91.3
250	96.4
350	106.2
200	96.4
100	87.0
0	75.0

Gauge Assembly #4

Load (lbs.)	Bridge Dial
0	2 - 1.0
50	5.4
100	11.9
200	19.7
250	25.8
350	35.7
250	30.7
100	14.5
0	3.5

Gauge Assembly #5

Load (lbs.)	Bridge Dial
0	1 - 136.2
50	146.5
100	153.2
100	2 - 6.6
200	18.2
250	22.9
300	27.9
350	31.4
200	20.1
100	10.4
100	1 - 158.5
0	145.3

Gauge Assembly #6

Load (lbs.)	Bridge Dial
0	1 - 125
50	131.7
100	137.3
200	153.6
200	2 - 7.0
250	12.3
270	13.2
200	9.5
200	1 - 156.4
100	148.6
50	141.6
0	134.1