MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

STUDY OF SUBSOIL PRESSURES BETWEEN ABUTMENTS AT GRADE SEPARATION STRUCTURES THE DETROIT INDUSTRIAL EXPRESSWAY, SECTION 3

By

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L. D. Childs

Research Project 44 E-10
Progress Report 1

Research Laboratory
Testing and Research Division
Report No. 67
May 14, 1945

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MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

E. A. Finney

INTEROFFICE COMMUNICATION

TO: W. W. McLaughlin May 21, 1945

SUBJECT: Report on Soil Pressure Studies at Grade Separation Structures X4, X7 & B13 of 82-22-10, Detroit Industrial Expressway, Section 3

In submitting the accompanying report an effort has been made to present as clearly as possible the preliminary results of soil pressure studies made at three grade separation structures located in Section 3 of the Detroit Industrial Expressway.

The principal objective of the Bridge Division is to measure the actual uplift soil pressures under the reinforce sub-base slabs, which are located between abutments. The Goldbeck pressure cells were installed to measure these soil pressures. The secondary objective is to measure the stress in the embedded reinforcing steel bars. The equipment installed for this purpose is the SR-4 strain gage, which depends on the principle of electrical resistance for its operation.

The data collected cover the first ten month period since the installation of the measuring equipment. The information obtained as registered by the Goldbeck pressure cells may prove to be very valuable. This phase of the investigation can be considered satisfactory. The results of the strain measurements of the reinforcing bars are not subject to simple rational interpretation. Other investigators have shown that strain gages attached to embedded reinforcing bars record stress very accurately until the concrete begins to crack and beyond this condition the correlation is erratic. It is evident that more experimental work is necessary.

In view of our experience with strain gage installations and stress measurements of embedded reinforcing steel it is suggested that the Highway Department conduct laboratory investigations to determine (1) an approved method of attaching and protecting surface strain gages that are to be used in connection with the measurement of stress in reinforcing steel embedded in concrete; (2) the correlation between actual stress and measured stress of reinforcing steel embedded in concrete. It is suggested that small reinforced test beams be used for this part of the investigation. It is hoped that results of such an investigation will aid in the interpretation of our present strain gage readings.

The collection of data over an extended period of time appears warranted in order to provide information on which to base more specific conclusions. The data thus accumulated should also provide a practical check on the theoretical soil mechanics analysis and computations.

G. O. Kerkhoff,
Asst. Engr. of Soils

GOK:GB

cc: F. S. Weber

FOREWORD

In the design and construction of the depressed sections of the Detroit Industrial Expressway, certain and necessary provisions were made to meet the anticipated critical soil conditions affecting both the roadway and the overhead structures. By way of checking the theoretical stress analysis within selected component parts of the overhead structures and the soils beneath, and also as an aid in future design studies, the Bridge Division recommended that pressure cells and strain gages be installed at three locations, namely, the N.Y.C.R.R. crossing, the P.M.R.R. crossing, and the Michigan Avenue Interchange structure.

During construction the Testing and Research Division of the State Highway Department installed Goldbeck pressure cells beneath the sub-base slabs that connect the abutments and piers of the above mentioned structures and also attached strain gages to the top and bottom steel reinforcing bars of these same slabs. A ten month record of the soil pressures and internal stresses that subsequently developed is given in graphical form which is attached to and is a part of the following detailed report covering objectives, installation details, comments, etc. The cell and gage readings are taken once a month and future recordings will become an addenda to this original report.

BRIEF SUMMARY

Preliminary soil mechanics computation indicated a possible uplift soil pressure of considerable intensity between abutments due to the surcharge back of the abutment and between wing walls. In order to make actual measurement of this anticipated upward thrust Goldbeck pressure cells were installed under the 24-inch reinforced concrete sub-base slabs. Uplift of the slab would logically elongate the reinforcing steel, so actual strain measurement of top and bottom bars has been attempted by attaching electric wire resistance strain gages to the bars. Pertinent information collected by means of the installed measuring devices during the first ten months is as follows:

1. All Goldbeck soil pressure cells are still in good working order.

2. Goldbeck soil pressure cells reflect static pressure caused by surcharge back of abutments and between wing walls.

3. Cumulative Expressway traffic appears to cause a variable increase in static soil pressure.

4. The largest increase in soil pressure is registered at the P.M.R.R. grade separation. We are informed that small cracks developed in the sub-base slab in the future north and south lanes.

5. Registered soil pressures are still variable and unpredictable. It is anticipated that soil pressures will become stabilized and approach a state of equilibrium.

6. Strain measurements in the top and bottom steel bars as registered by the strain gages are erratic and do not seem to follow a rational pattern. However, continuation of strain gage readings is recommended in order to determine their merit, the life of this type of gage, and to prove or disapprove the method of application and installation.

Purpose of Project

The principal purpose of this investigation is to measure upward soil pressures under sub-base slabs between abutment footings. The tendency of the clay to move upward is due to the pressure resulting from the surcharge behind the abutment and between the wing walls. The theoretical analysis of the soil stability as effected by the abutment surcharge is of some complexity and at some structures the index of overload ratio of the yield point of the cohesive soils indicated a trend toward possible uplift within the roadway area. The soil mechanics analysis is based on the ring shear test, which determines the ultimate elastic yield point of cohesive soils. The tests are made on undisturbed soil samples in the Highway Laboratory at Ann Arbor.

Because of the critical soil conditions in Section 3 of the Detroit Industrial Expressway the Bridge Division adopted a design incorporating a reinforced concrete sub-base slab anchored to the abutment and pier footings and extending continuously from abutment to abutment and to the full width of the footings. These sub-base slabs are designed to function as struts between abutment and pier footings and the weight of the concrete is employed to aid the passive resistance of the soil to offset any uplift movement in the roadway section.

In order to benefit future proposed construction across the City of Detroit and in similar plastic clay deposits it was planned to check theo-

retical soil mechanics computations with actual measurements. Consequently, the Testing and Research Division was requested to install pressure cells under the sub-base slabs and strain gages in the concrete in such a manner that soil pressures under the sub-base slabs and stress within them could be studied. The N.Y.C.R.R. (main line), the P.M.R.R. (main line), and the Michigan Avenue Interchange grade separation structures were selected for this investigation.

PART I

PROGRESS OF THE INVESTIGATION

The pressure cells and the strain gages have been in place seven to nine months. This period covers the construction phase, completion of the structure, traffic on the superstructure, and the opening of the Expressway to vehicular traffic. The interval between readings of the pressure cells and strain gages is approximately one month. Assuming that the pressure cells and the strain gages are in good working order and that the readings are an accurate indication of the variations in pressure and strain, the following facts appear to be evident:

N.Y.C.R.R. Grade Separation (Project X4 of 82-22-10)

1. Strain Gages - South Lane Location

   (a) During the construction period including the time of curing of the sub-base slab, the top and bottom reinforcing bars registered a somewhat complex and variable state of strain.

   (b) Near the completion of the structure and with the advent of railroad traffic over the bridge, a more uniform pattern of strain developed in the reinforcing bars located in the sub-base slab.

   (c) Bottom reinforcing bars registered a uniform state of compression, approximately equal in intensity.

   (d) Top reinforcing bars registered a complex condition of compression and tension in each bar. Surface gages on the vertical sides of top bars showed that these bars have the same degree of compression as the bottom bars

and the gages on the top surfaces of these bars registered a state of tension. This condition seems inconsistent with expectations and later measurement may shed more information on this unusual state of strain.

Interpretation of the strain gage measurements seems to indicate a possible inward thrust of the abutment footings tending to place the sub-base slabs in a state of compression.

A trend toward internal stress equilibrium appears to be developing at the present time.

2. Pressure Cells - South Lane Location

The subsoil pressure under the sub-base slab increased gradually during the construction period and continued during the first few months of railroad traffic. This soil pressure dropped considerably during the cold winter months, e.g., soil pressure near the footing of the center pier indicated no pressure. The center of the sub-base span reverted back to its original soil pressure. Near the abutment footing the soil pressure dropped to a negligible value.

With the advent of spring - warmer weather and considerable rain - along with the opening of the Expressway to traffic a noticeable change in soil pressure developed; all pressure cells registered a definite increase in soil pressure.

To draw conclusions regarding sub-base soil pressures based on observations covering a short period of ten months may be hazardous and speculative. The pressure cells are functioning satisfactorily and the results seem reasonable. The unexpected drop in soil pressure during the winter months seems unexplainable at present. We could expect a retarding action due to frost penetration and a resumption of increased static soil pressure with warm weather, especially during a wet season. The pressure cells do indicate that the sub-base soil pressure is not in a state of equilibrium. Monthly readings are still variable. However, it is expected that in due time, the subsoil pressure will become stabilized.

P.M.R.R. Grade Separation (Project X7 of 82-22-10)

1. Strain Gages

(a) South Lane Location

The strain gages were attached to the top and bottom reinforcing bars three days after the sub-base slab was poured. Stress conditions in the reinforcing bars as registered by the strain gages show variations at each monthly reading. A somewhat complex pattern of stresses was recorded during the construction period, the advent of railroad traffic, and the first month of vehicle traffic over the Expressway. We can expect that in time the stresses within the sub-base slab will indicate a more uniform and definite trend.

(b) Future Lane Location

Strain gages were attached to four reinforcing bars before they were assembled in the reinforcing steel mat. Immediately after pouring of the sub-base slab the strain gages were read. Stress conditions in the reinforcing bars as recorded by the strain gages show a changing state. This may be due to the complex effect of increased soil pressure, early curing stresses, additional loadings as construction progressed, abutment and sub-base slab backfilling, railroad traffic, and finally Expressway vehicle traffic. Although the stress pattern of the top and bottom reinforcing bars is not uniform, nearly all bars appear to be in a state of tension. Again we can expect that in time the internal stresses in the sub-base slab will stabilize and show a definite pattern.

2. Pressure Cells

(a) South Lane Location

There is a definite increase in soil pressure under the sub-base slab. The greater part of the increase in soil pressure developed immediately after the placing of the backfill at the south abutment and during the building

of the bridge deck. The maximum soil pressure beneath the slab span is at the south end adjoining the south pier and decreases gradually toward the north end (center pier). At present the soil pressures appear to be in the process of approaching a uniform static equilibrium. We do note a slight general decrease in soil pressure in recent observations.

(b) Future South Lane

There has been a definite increase in soil pressure under the sub-base slab. Approximately 95 per cent of the soil pressure increase was developed immediately after the placing of the backfill at the south abutment. It is noted that the center of the sub-base span continued to show an increase in soil pressure until the sloping backfill over the sub-base was completed. At present the soil pressure is of uniform intensity across the full length of the sub-base span. At present the soil pressures appear to be in the process of approaching a state of uniform static equilibrium. We are informed that a definite pattern of cracking developed in the sub-base slab before November, 1944. This was before the sloping backfill over the south sub-base slab was placed. This may be the result of early increased soil pressure below the sub-base slab plus a probable effective state of compression caused by an inward abutment thrust.

Michigan Avenue Interchange (Project B13 of 82-22-10)

1. Strain Gages

(a) Center Location

Strain gages were read four days after the pouring of the sub-base slab. This first set of readings provided reference points for subsequent data. The strain gages reflected a sharp change in stress in the reinforcing bars during the bridge construction period and with the advent of Michigan Avenue street car and vehicle traffic over the structure. The last four monthly readings (December 19,

1944 to March 28, 1945) indicate a fixed condition of stress in the reinforcing bars. The top and bottom reinforcing steel register large tensile stresses. This unusual complex state of stress is unexplainable at present. It does appear that the sub-base slab is in a state of tension between the abutment footings.

(b) South End Location

Strain gages were installed at the same time and under similar conditions as were the units at the center location. The strain gages registered a variable state of stress in the reinforcing bars at each monthly reading. The stress in the steel bars since the pouring of the sub-base slab registers only minor changes. The majority of the reinforcing bars are in tension which may indicate that the sub-base slab is in tension between the abutment footings. The pattern of the stress curves for the reinforcing bars is complex and no interpretation of the results will be made at this time.

2. Pressure Cells

(a) Center Location

The soil pressure under the sub-base slab showed a slight increase during the construction period and during the first two months of the Michigan Avenue traffic. Since then the soil pressure has gradually decreased by 100 to 200 pounds per square foot below the amount it registered at the time the sub-base slab was poured. This would indicate that the sub-base slab is not receiving the same support from the subsoil as it was at the time of its construction. It is anticipated that the full effect of confined soil pressures will be realized later when the variable layers of the backfill materials become fully consolidated. This partial loss of the subsoil support for the sub-base slab must be supplied by the abutment footings. It can be deducted that the center of the sub-base slab might settle at first, a reverse condition from that anticipated in design.

(b) South End Location

The subsoil pressure increased slightly during the construction period but did not reflect any increased pressure with the advent of street car and vehicle traffic on Michigan Avenue. There is a gradual decrease in subsoil pressure from 200 to 300 pounds per square foot as compared with the soil pressure at the time of construction of the sub-base slab. Apparently the same comments regarding the center location apply also to the south end of the sub-base slab.

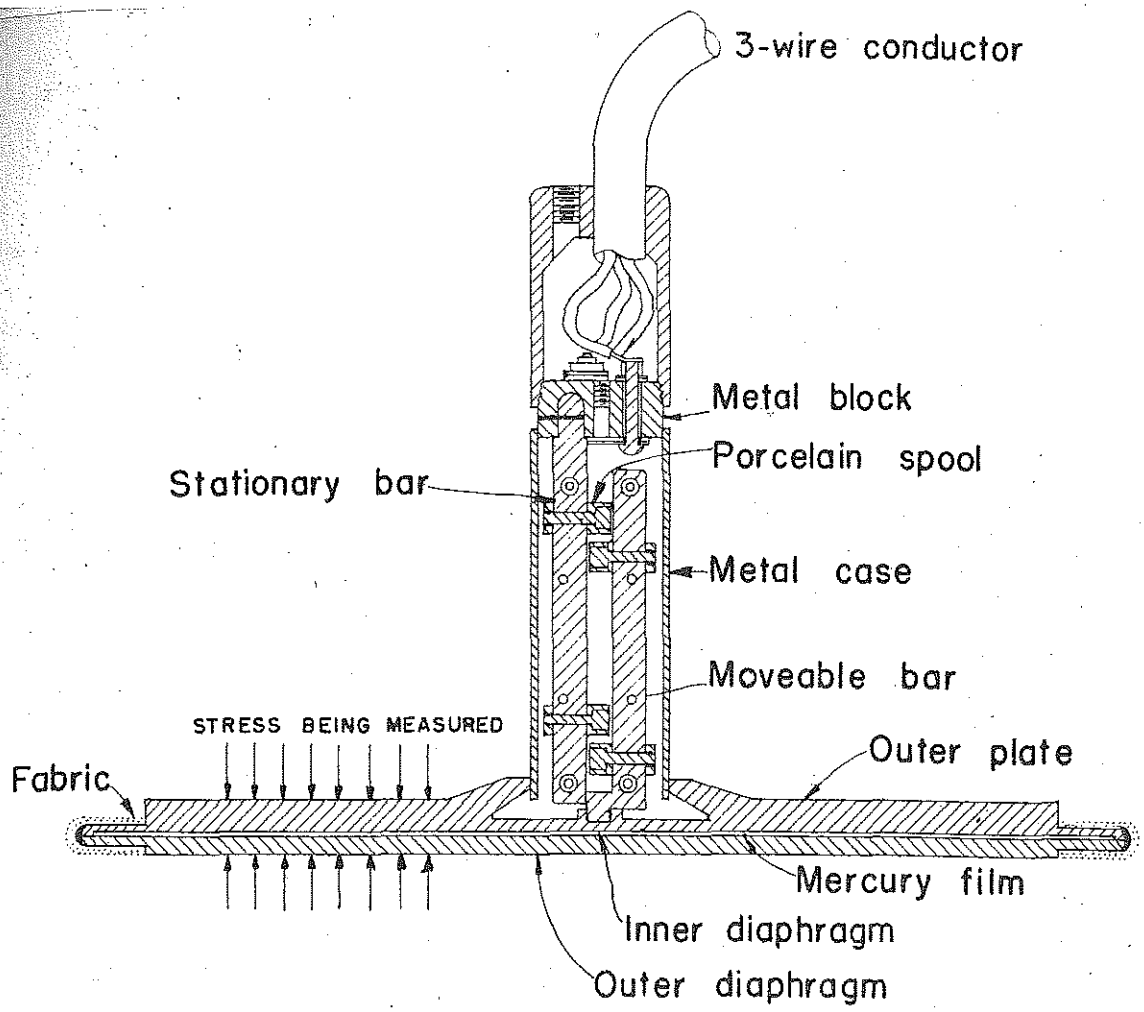
PART II

PRELIMINARY INVESTIGATION AND PREPARATION

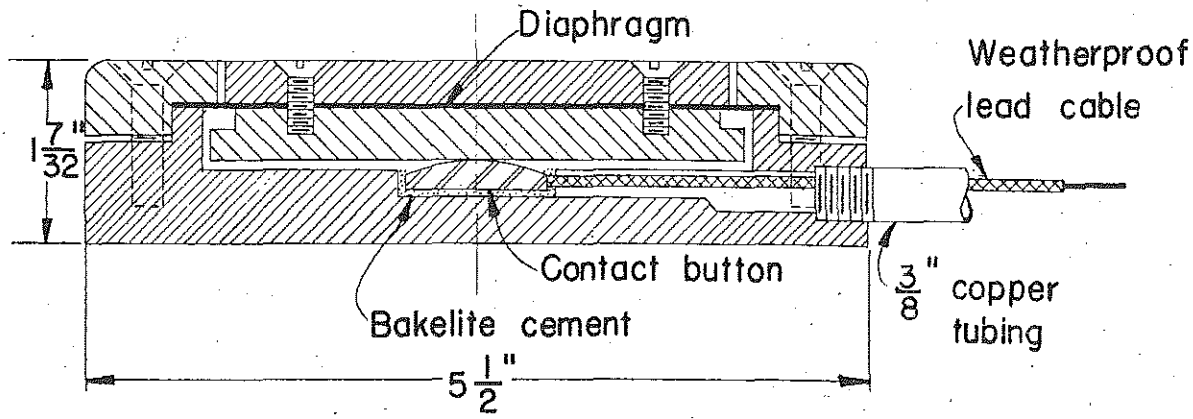
A number of inquiries were made concerning the various types of cells which could be used to indicate bearing pressures. Several reports[1] on pressure cell investigations were studied. It was concluded that an adaptation of the Carlson Stress Meter (Plate #1) would be likely to give the most reliable and accurate information over a long period of time. However, these meters were not available so the standard Goldbeck Pressure Cell (Plate #1) was chosen, though this necessitated the installation of a pneumatic line as well as an electrical circuit.

It was thought that measurements of internal stresses in the sub-base slabs would complement the readings of the pressure cells beneath the slabs. A strain gage was desired which would reliably indicate the extent and direction of these stresses and be readable after the roadway slab had been laid over the sub-base. These limiting conditions precluded any installation which required measurement by mechanical means, so the electric gage[2] was considered.

The Carlson gage[3] had proved very satisfactory on the Michigan Test Road, but such gages could not be procured. The Baldwin-Southwark SR-4 gages[4] were investigated and it was decided that they would give satisfactory results if properly attached to the reinforcing steel and protected from moisture. Accordingly, an arrangement was made with the Department of Engineering



CROSS-SECTION OF CARLSON STRESS METER



CROSS-SECTION OF GOLDBECK PRESSURE CELL

SCALE: 3/4" = 1"

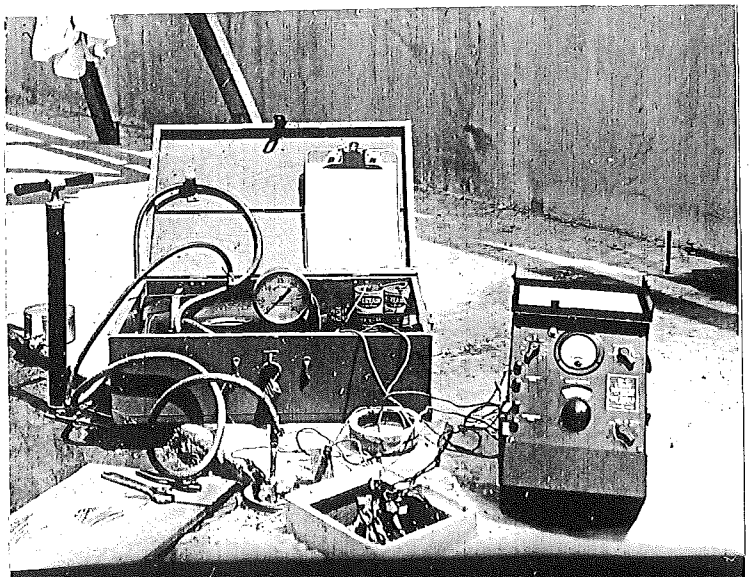
PLATE #1

Mechanics at the University of Michigan to provide a sufficient number of type A-5 gages and to supervise their installation.

The State Highway Soil Mechanics Laboratory personnel assmed the responsibility for the preparation and installation of the Goldbeck pressure cells. These cells were fitted with heavy duty 3/8-inch copper tubing and power brake pipe fittings and a well insulated copper wire (auto primary multiple strand) was run from the contact button through one tube to the reading station located just above the ground surface.

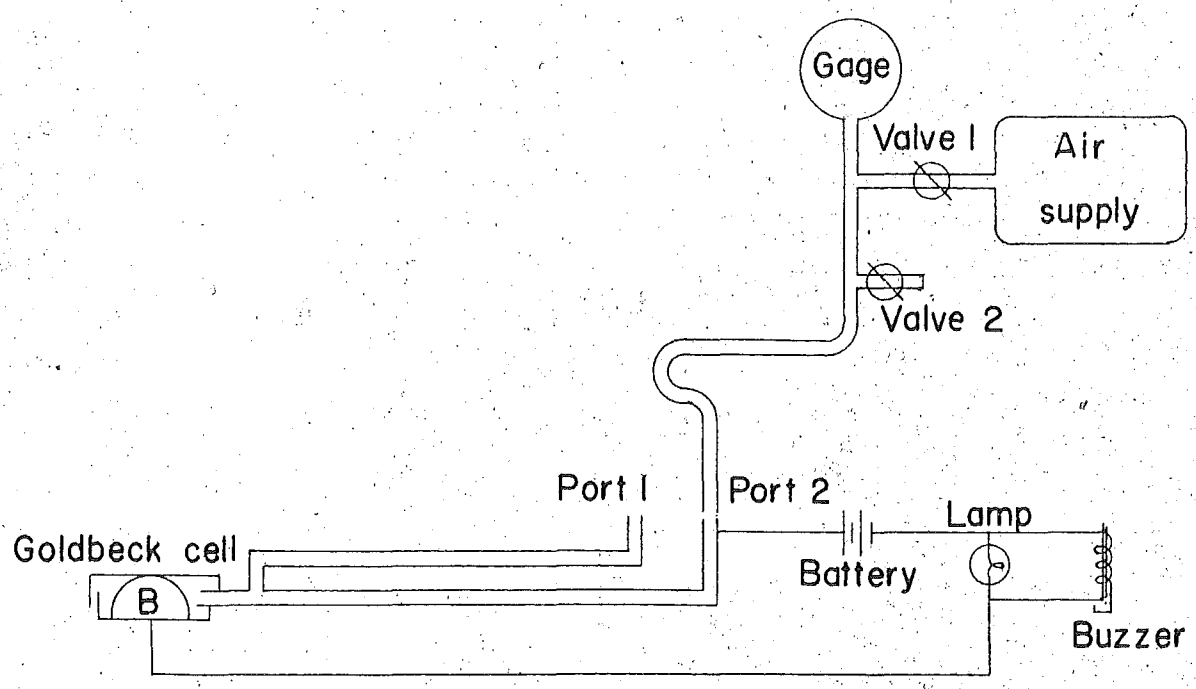
The auxiliary equipment necessary to measure the soil pressure consists of a compressed air tank, a pressure gage, control valves, an electric buzzer and batteries. This apparatus was assembled in a portable case and is shown in Photograph #208. A schematic diagram of the pressure cell and necessary accessories are given in Plate #2.

The procedure for recording the pressure exerted on the cell is as follows: Air is pumped through Port 1 with a hand pump to force any condensed moisture out of the system at Port 2. Port 1 is then plugged, a valve stem is screwed into Port 2, and the air hose from the indicating unit is connected. The electrical circuit is completed as shown, the lamp lights and the buzzer begin to sound. Valve 1 is opened and air enters the cell under pressure. When sufficient pressure is built up to expand the cell until the piston breaks contact at button B, the lamp goes out and the buzzer stops sounding. Valve 1 is closed immediately and the gage is read.



No.208 Set up at reading station showing Soil pressure.Cell and Electric Strain Gage measuring equipment. X4 of 82-22-10 NYCRR

PHOTOGRAPH #208



SCHEMATIC DIAGRAM OF PRESSURE RECORDING EQUIPMENT

PLATE #2

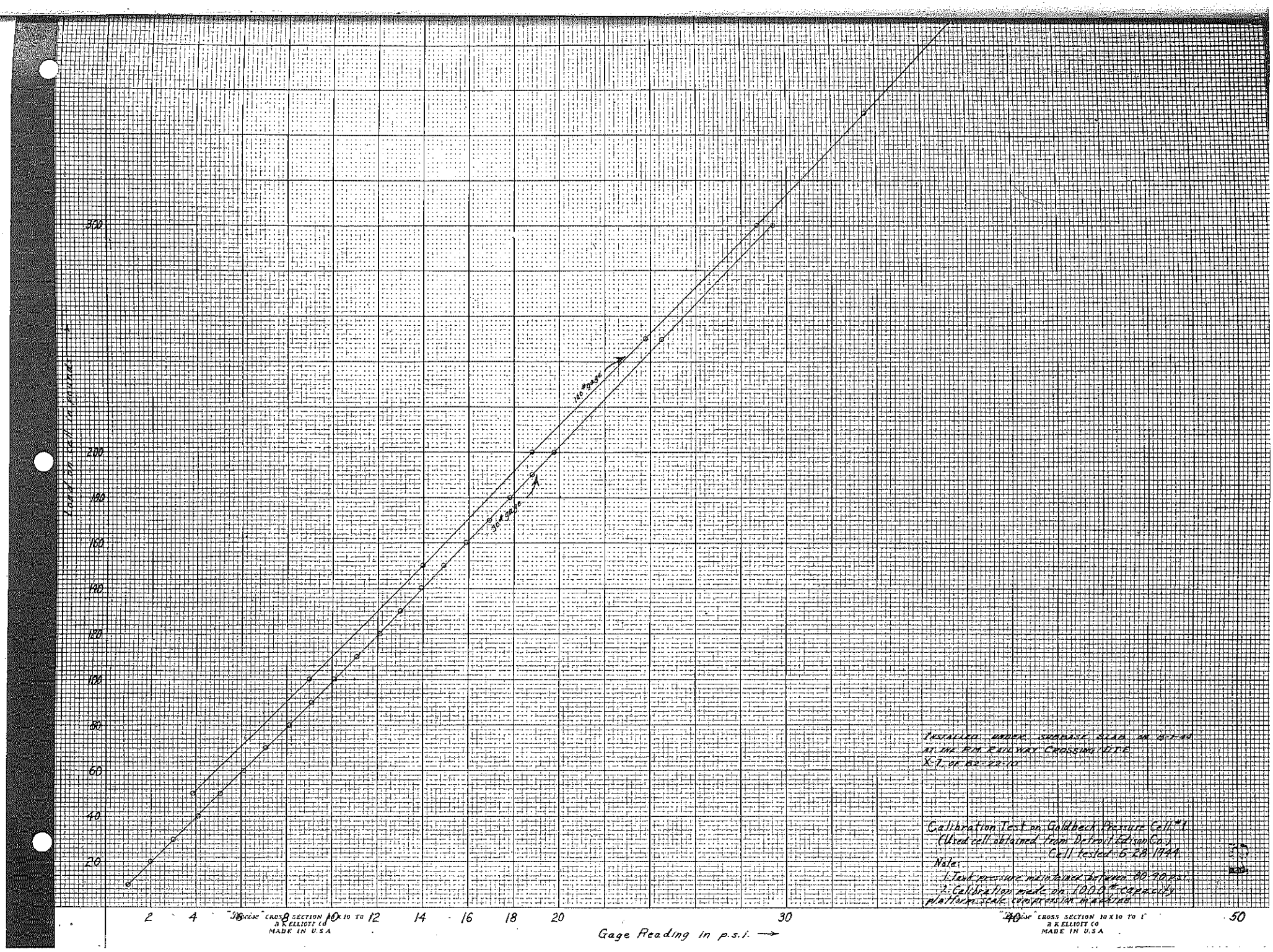
Some air is now exhausted through Valve 2 until the pressure in the system is reduced well below maximum. Then Valve 2 is closed, Valve 1 is opened and the process is repeated. The reading recorded in the notes is the average of several of these trials.

Since the area of the piston in the Goldbeck cell is 10 square inches, the soil pressure in pounds per square foot is given by the formula,

$$P = 14.4 \times \text{gage reading}$$

Each pressure cell was calibrated in the laboratory before it was approved for installation. These calibration curves were run for both the low pressure and high pressure gages incorporated in the indicating unit. A typical calibration curve is shown on Plate #3. Calibration curves are used to correct pressure cell field readings.

The SR-4 electric strain gage (Plate #4) is a small grid of fine wire, the resistance of which increases with elongation and decreases with compression. The wire grid is cemented to paper and covered with a felt pad to provide protection during application. This gage is attached to the material to be stressed with an approved type of cement. After the cement has dried, insulated wires are attached to the gage terminals and led to an indicating device. This device is a sensitive resistance bridge, and the change in gage resistance can be read in ohms and converted to strain. A specially designed indicator may be used which reads strain directly in micro-inches per inch. This latter instrument, called the SR-4 Portable Strain Indicator,



Load on cell in pounds
300
200
180
160
140
120
100
80
60
40
20
2
4
6
8
10
12
14
16
18
20
30
40
50
Gage Reading in p.s.i. →
140# gage
30# gage
INSTALLED UNDER SUBBASE SLAB ON 8-1-44
AT THE P.M. RAILWAY CROSSING D.T.E.
X-7, OF 82-22-10
Calibration Test on Goldbeck Pressure Cell #1
(Used cell obtained from Detroit Edison Co.)
Cell tested 6-28-1944
Note:
1. Tank pressure maintained between 80-90 p.s.i.
2. Calibration made on 1000# capacity platform scale compression machine
"Precise" CROSS SECTION 10 X 10 TO 1
B K ELLIOTT CO
MADE IN U.S.A.

PLATE #3

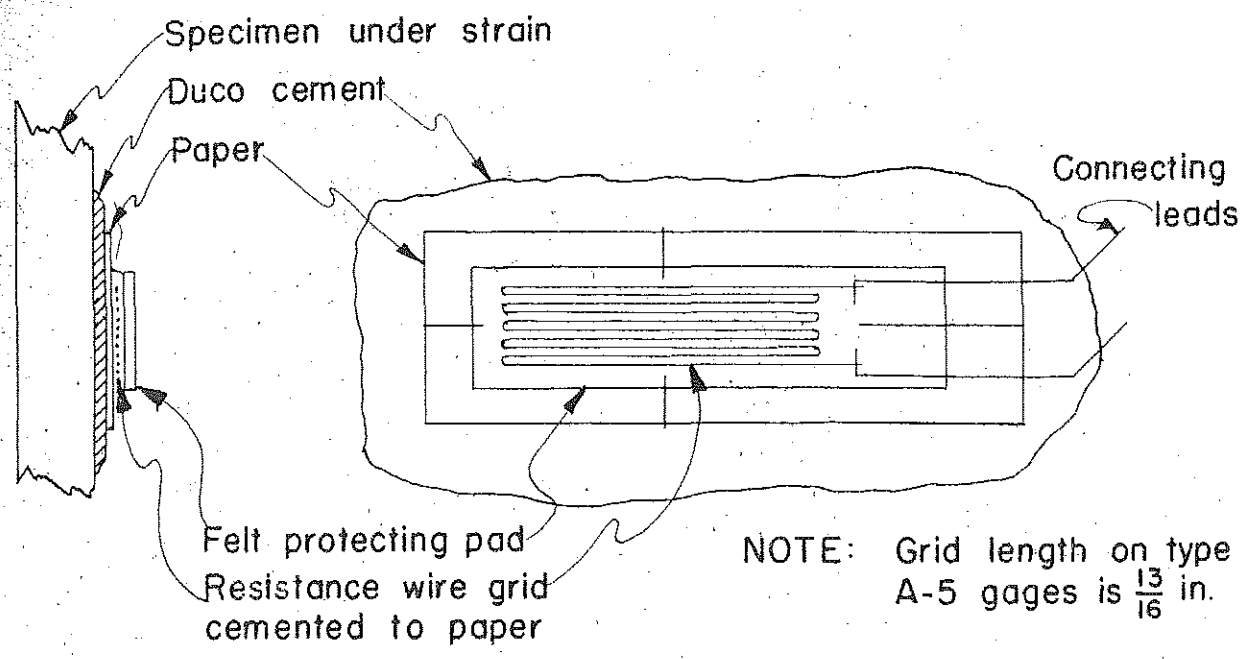
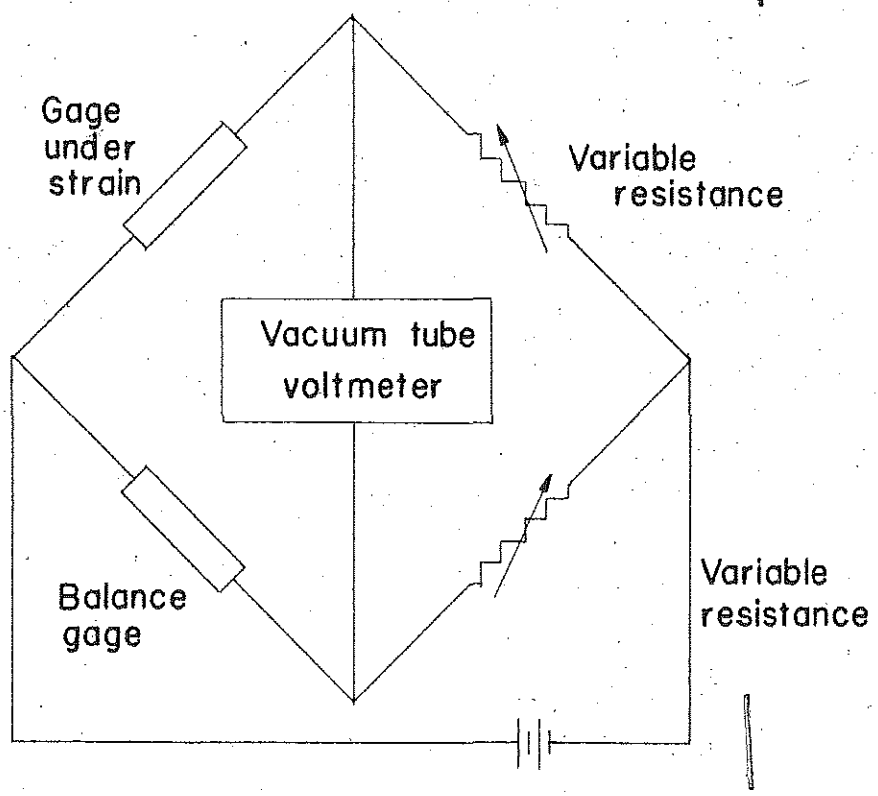


DIAGRAM OF SR-4 ELECTRIC STRAIN GAGE

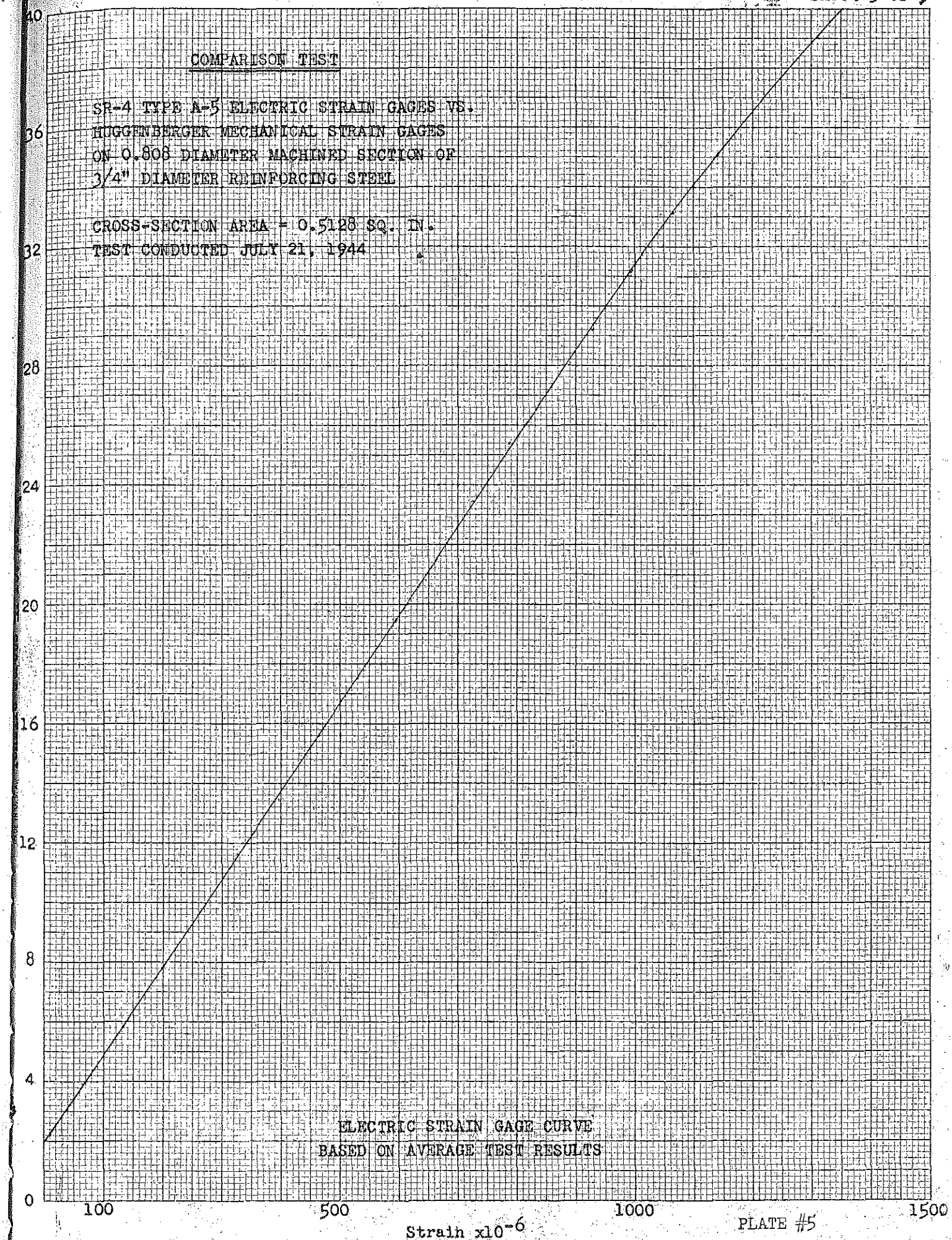


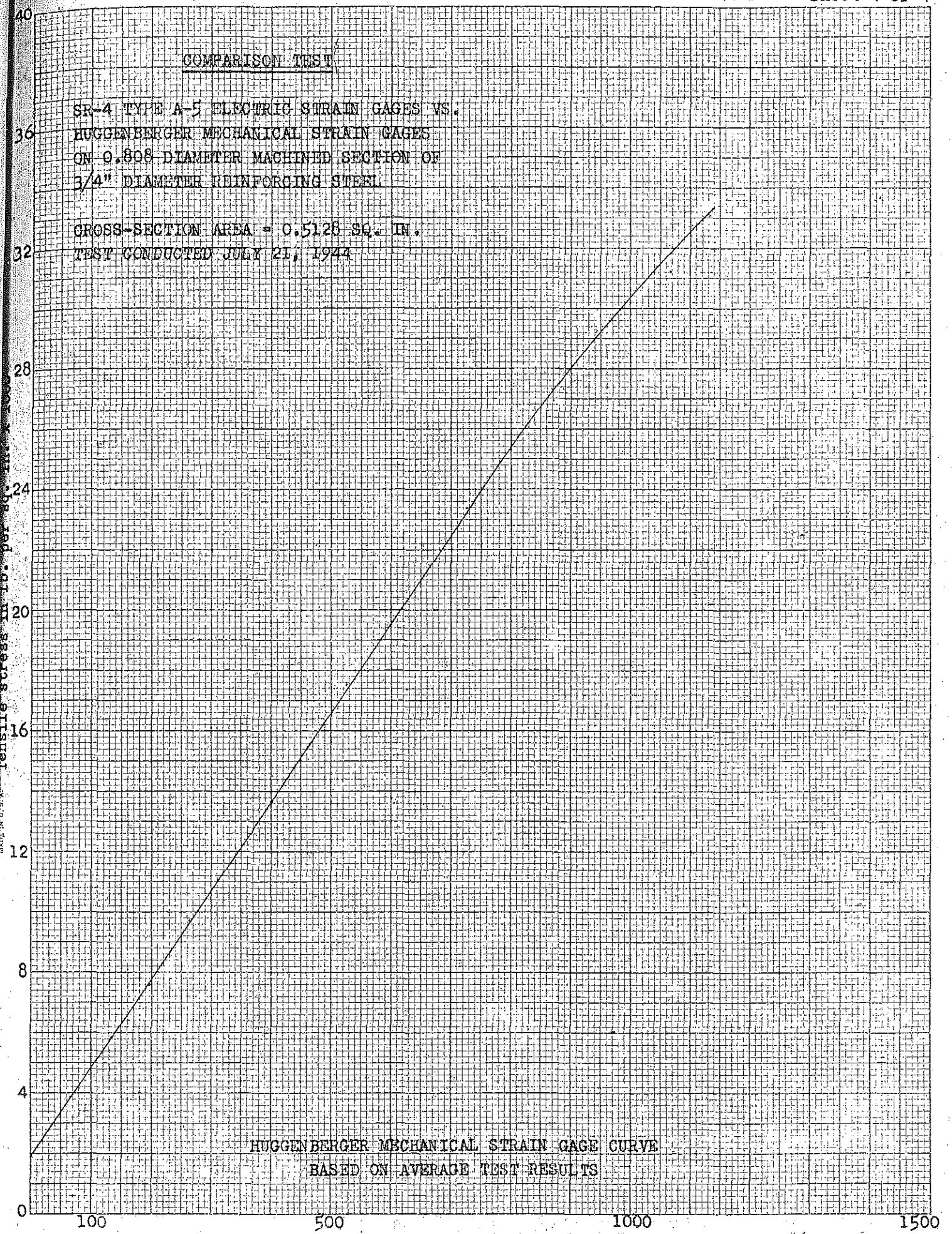
SCHEMATIC DIAGRAM OF STRAIN RECORDING DEVICE

was used throughout this test. A schematic diagram of the electrical circuit is shown on Plate #4. In order to avoid errors due to temperature changes a dummy or compensating gage is used as one arm of the resistance bridge. This gage is of the same type as the one to be measured. It is mounted upon an unstressed section of the material under test, and kept at the same temperature as the stressed action.

A check test was made to determine the correlation between strains as recorded by the SR-4 gage and indicator, and the mechanical Huggenberger gage. A reinforcing bar of the type used in the construction of the structures under test was obtained and a section machined to provide a length with uniform cross section. An electric gage was attached as described and the rod was clamped in a tension machine. The Huggenberger gage was attached and readings taken for various loads with both instruments. The calibration curves are shown on Plates #5 and #6.

In order to use the SR-4 gages as internal strain indicators it was necessary to devise some means of protecting them from direct pressure and from the moisture and chemical action of the concrete. After some experimentation the protection was applied as follows: When the gage was freshly cemented to the reinforcing bar, it was wrapped with electrician's rubber tape. This performed the function of maintaining pressure upon the bar to aid in forming a good bond as well as providing weathering protection. After the drying period had elapsed, the lead wires were attached to No. 18 SN single wire


COMPARISON TEST
SR-4 TYPE A-5 ELECTRIC STRAIN GAGES VS.
HUGGENBERGER MECHANICAL STRAIN GAGES
ON 0.808 DIAMETER MACHINED SECTION OF
3/4" DIAMETER REINFORCING STEEL
CROSS-SECTION AREA = 0.5128 SQ. IN.
TEST CONDUCTED JULY 21, 1944
40
36
32
28
24
20
16
12
8
4
0
100
500
1000
1500
Strain x10-6
ELECTRIC STRAIN GAGE CURVE
BASED ON AVERAGE TEST RESULTS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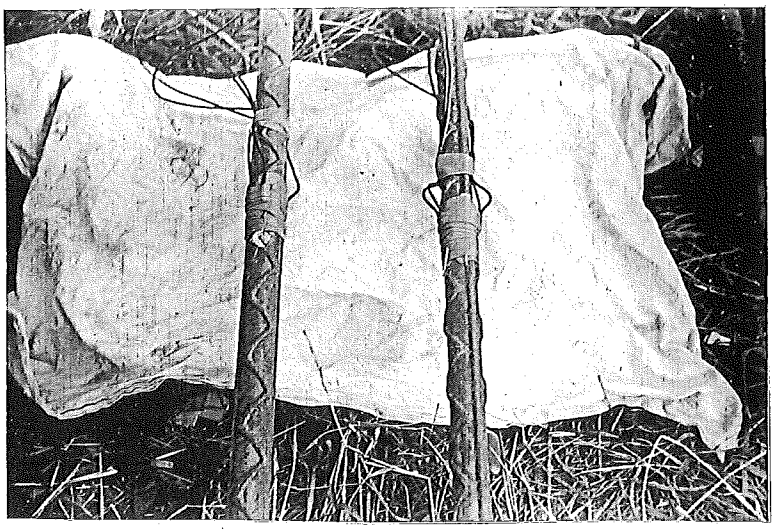
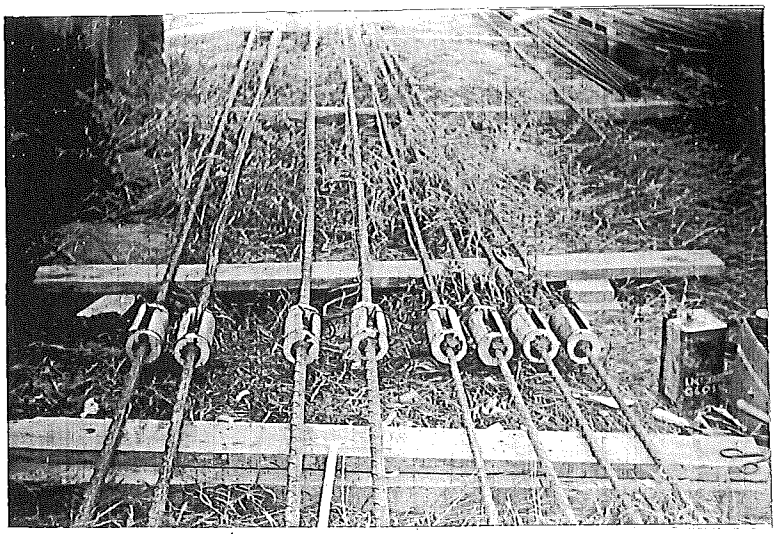
HUGGENBERGER MECHANICAL STRAIN GAGES
ON 0.808 DIAMETER MACHINED SECTION OF
3/4" DIAMETER REINFORCING STEEL
CROSS-SECTION AREA = 0.5128 SQ. IN.
TEST CONDUCTED JULY 21, 1944
HUGGENBERGER MECHANICAL STRAIN GAGE CURVE
BASED ON AVERAGE TEST RESULTS
Tensile stress in lb. per sq. in. x 1000
0
4
8
12
16
20
24
28
32
36
40
100
500
1000
1500
Strain x10^-6

PLATE #6

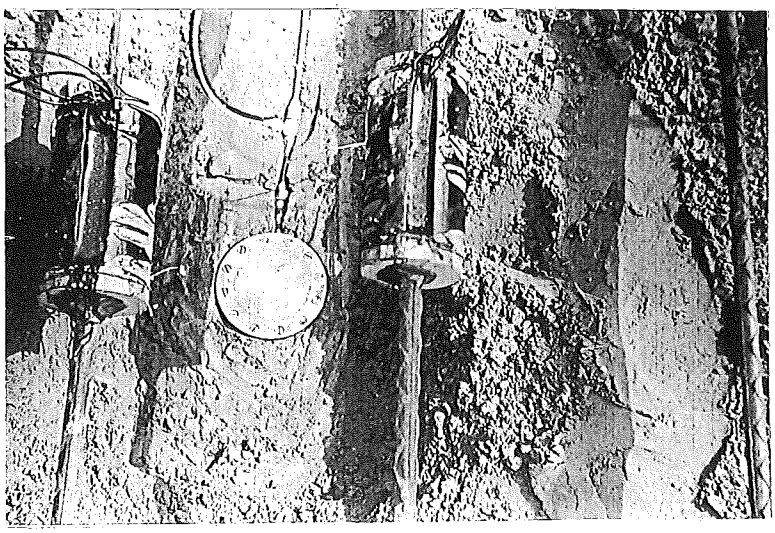
and a metal shield was fastened to the bar. This shield was poured full of an asphaltic compound (WOA) at as low a pouring temperature as possible. It was found upon examination of trial specimens that the heat from the asphaltic compound caused the rubber tape to vulcanize, but the temperature was still below the critical value for the gage. Photographs #2, #3 and #4 illustrate this weatherproofing operation.



PHOTOGRAPH #2



PHOTOGRAPH #3



PHOTOGRAPH #4

PART III

INSTALLATION DETAILS

1. The New York Central Main Line Railroad Grade Separation over Section 3 of the Detroit Industrial Expressway was the first bridge to incorporate pressure cell and strain gage installations in its construction. It was originally planned to place three pressure cells on the soft blue clay beneath the sub-base at two locations in the south lane. These positions were to be approximately beneath a main track and at each edge and the center of the sub-base slab span. The strain gage assembly was to be directly above the center cell location in each case.

Construction proceeded at too rapid a pace to allow time for the two installations as planned. Difficulty was encountered in obtaining supplies, especially moisture-proof insulated electrical wire. However, one set of pressure cells were installed and a 2-foot square section was boxed out for later strain gage installation. Each cell was placed with the moveable piston against the clay and pressed down until well seated in the very smooth soft blue clay. Concrete was then placed over the cell during the pouring of the sub-base slab. There was a delay of approximately one month before the strain gages were attached to the reinforcing bars. This was due partly to construction interference but mainly because of a head of water in the sand sub-base below the sub-base slab which was troublesome when attempting to maintain a dry hole when attaching the strain gages. Two strain gages

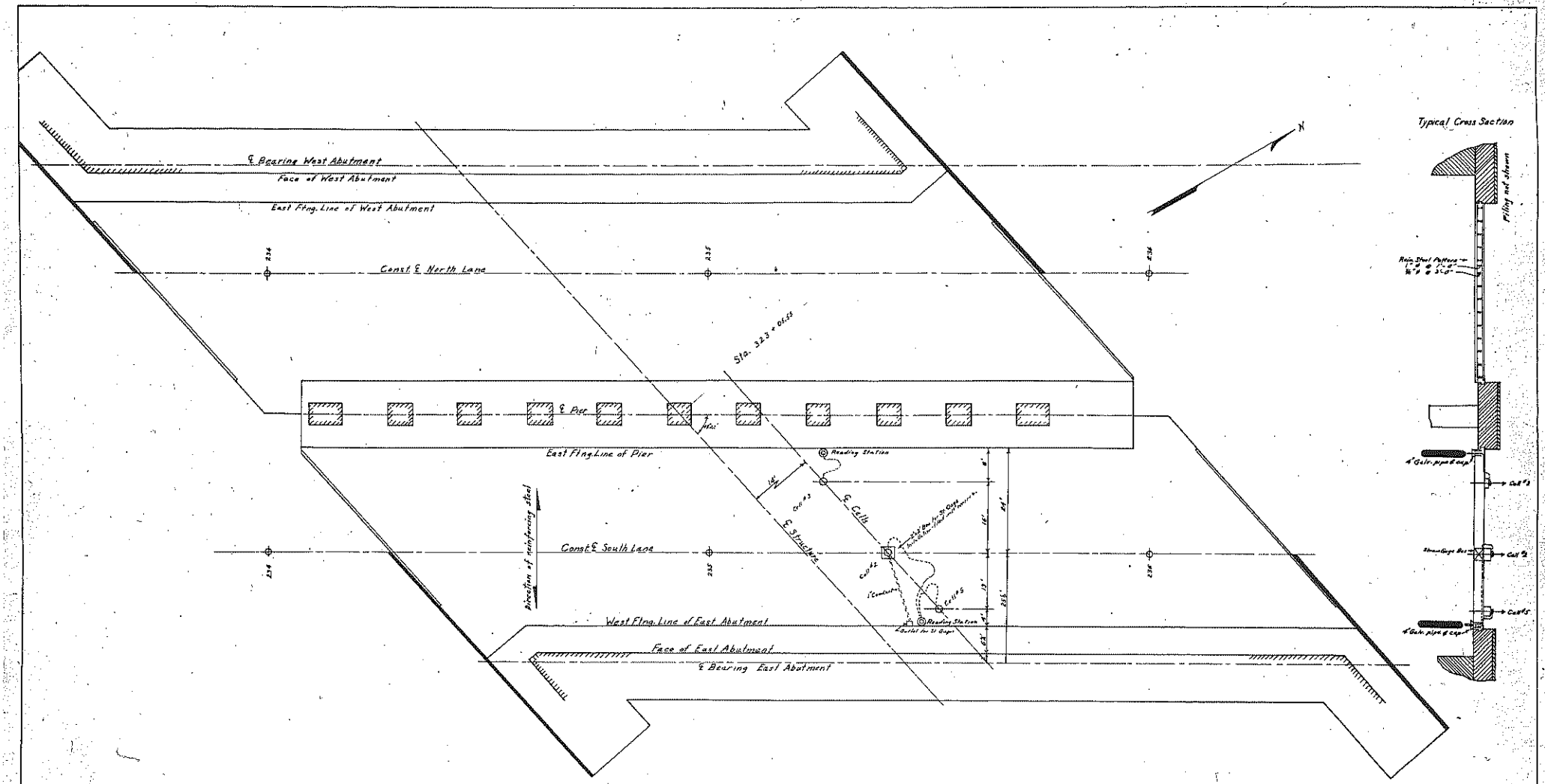
were attached to each bar to assure against loss of any one gage. Although it was thought that gages placed on the vertical side of the bar would give more nearly equal strain measurement, it was not feasible to do so in the limited working space, so in this installation each bar has one gage on the top and one on the side. (See Plate #7.)

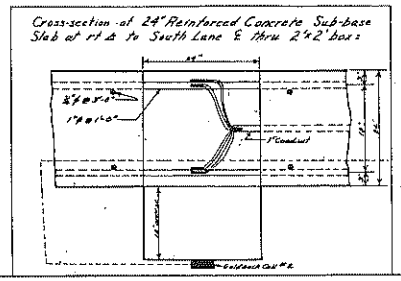
On July 11, 1944, the gages were attached to the bars and the cementing glue was allowed to dry overnight. The following day they were wired, sealed in (WOA) and the initial readings were readings were recorded. Later the 2 by 2 ft. boxed out hole was filled with concrete. The Goldbeck pressure cells were also read at this time.

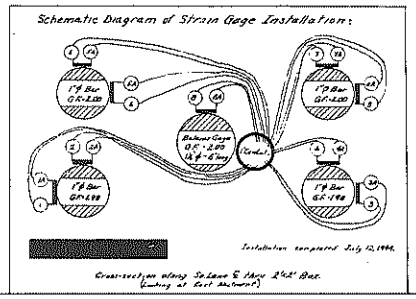
Plate #7 shows the Goldbeck pressure cell locations and numberings, the reading station position, the strain gage numberings and positions, and the dimensions of the slabs. These gage and cell identification numbers are referred to on the data sheets throughout the remainder of this investigation.

Available construction photographs showing foundation work are attached in Part V of this report.

2. The P.M.R.R. Grade Separation was the next location where testing equipment was installed to measure the subsoil pressures. This is a large four span structure. It was planned that present Expressway vehicular traffic should flow beneath the two center spans, while the space below the outer spans was to be filled with an earth embankment and sloped to conform to the cross section of the depressed roadway.







Note:
Goldbeck Pressure Cells installed June 10, 1944.

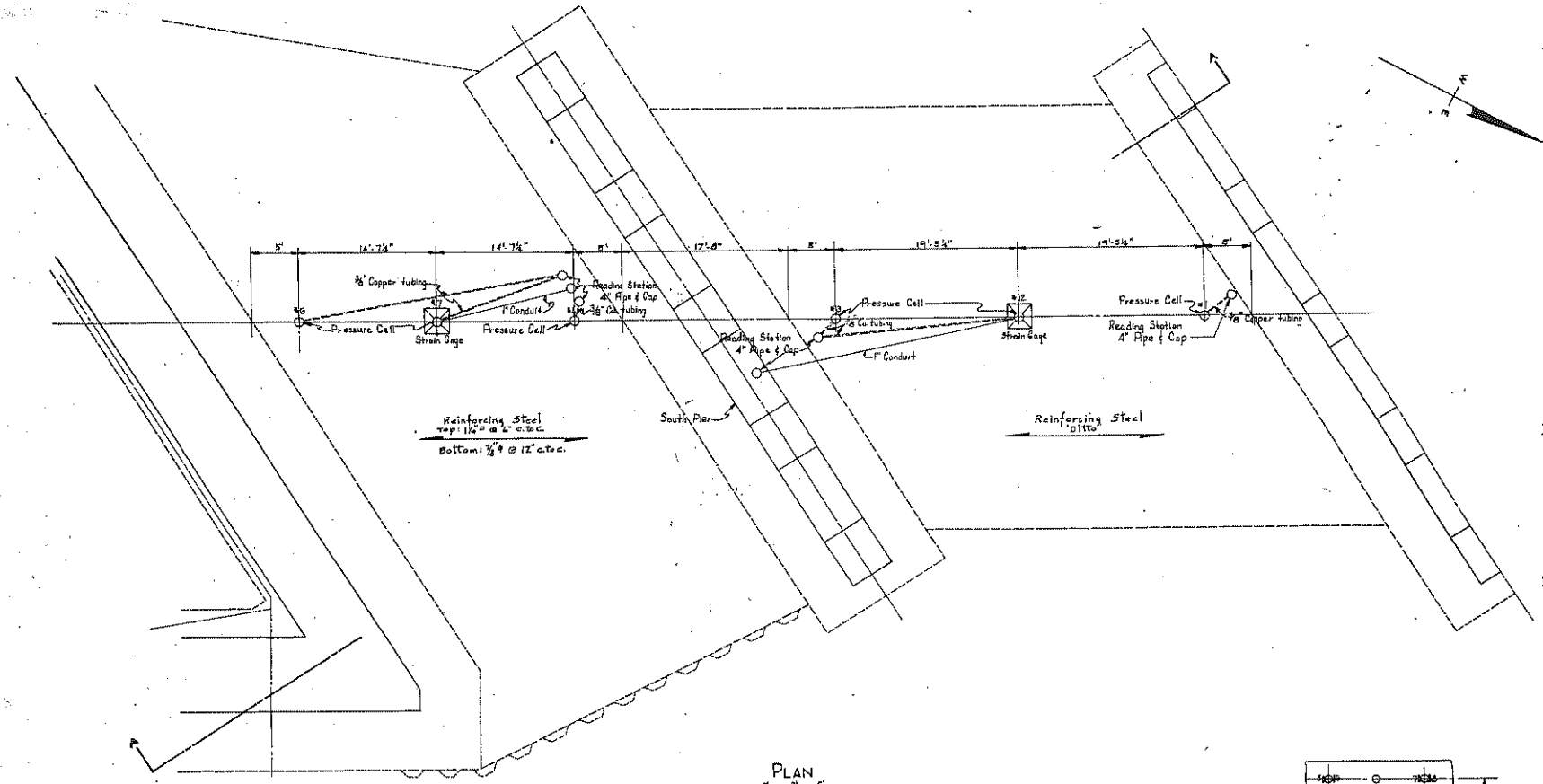
MICHIGAN STATE HIGHWAY DEPT.
CHARLES M. ZIEGLER
STATE HIGHWAY COMMISSIONER

LOCATION OF GOLDBECK PRESSURE CELLS AND BALDWIN-SOUTHWARK ELECTRIC STRAIN GAGES.
N.Y.C.R.R. MAIN LINE CROSSING D.I.E. (SECTION 3)
PROJECT X4 OF 82-22-10
INSTALLATIONS MADE BY SOILS MECHANICS LABORATORY
DRAWN BY A.C.G. (7-10-1944) APPROVED BY G.D.K.

PLATE #7

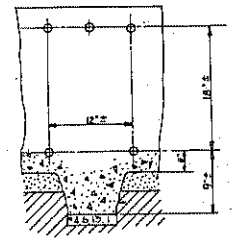
Plate #8 shows the location of the pressure cell and strain gage installations. Three pressure cells were installed beneath the sub-base under the south center span, and three more cells were placed under the south end span (future lane). Cross-sectional views revealing the depths necessary to assure contact between the blue clay and the pressure cells are shown in Plate #8.

(a) At the present south lane location construction progress made it necessary to box out a 2 by 2 ft. opening in the sub-base slab to make it possible to attach the strain gages to the reinforcing bars. A one-inch diameter electrical conduit pipe was installed connecting the boxed out opening with the reading station. Three days later the strain gages were attached to the top and bottom reinforcing bars and the cementing glue allowed to dry overnight. The next day the gages were wired up, enclosed in metal sleeves and sealed with asphaltic compound (WOA). The compensating gages (dummy gages) were centered between the top and bottom bars. They were attached to a 6-inch length of unconnected reinforcing bar centered in a metal container and sealed in WOA to eliminate outside stresses. The 2 by 2 ft. boxed out opening was then filled with concrete. All strain gages were checked and found to be in good working condition. First complete initial readings were taken three days later, August 10, 1944.



PLAN

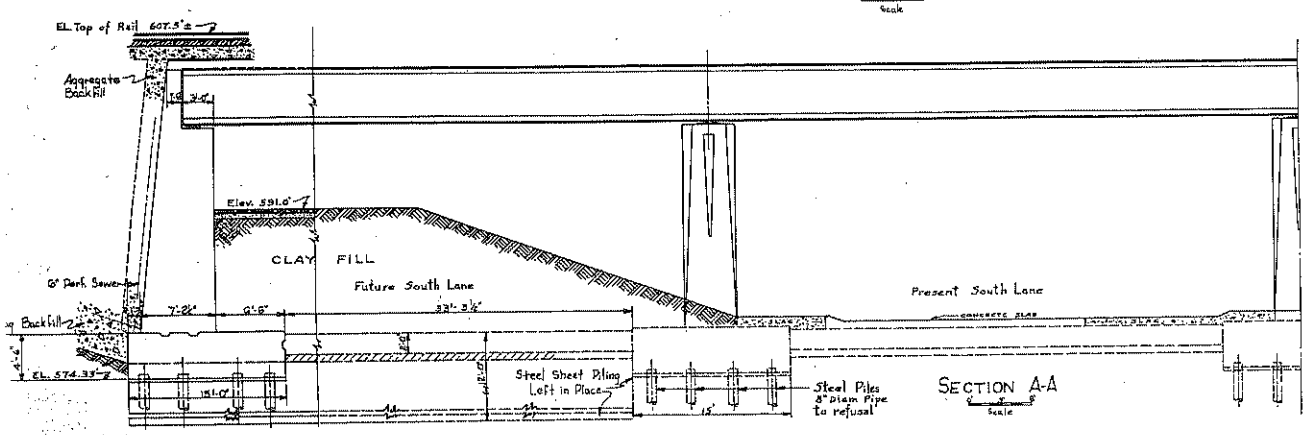
Scale



Installation of Pressure Cells #4, 6, 13, 1
View Toward South Pier

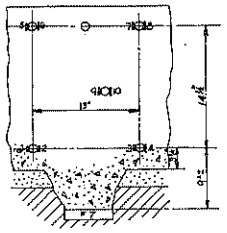
Scale

NOTE: Goldbeck pressure cells & Baldwin-Southwark strain gages used.



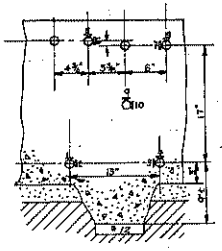
SECTION A-A

Scale



Installation of Pressure Cell # 7
With Strain Gages
View Toward South Pier

Scale



Installation of Pressure Cell #12
With Strain Gages
View Toward South Pier

Scale

PERE MARQUETTE CROSSING AT D.I.E.

PRESSURE CELL & STRAIN GAGE INSTALLATION

Project X 7 of 82-22-10

Inst. completed 8-9-44

Details Corrected 4-20-45 G.O.K.

Drawn: 1-29-45 S.A.V.

The pressure cells were installed just prior to the pouring of the sub-base slab on August 3, 1944. Each cell was so placed that the moveable piston face was seated in the blue clay. Concrete was well packed on top of the cell during the pouring of the slab. All three cells rest on uniform smooth soft silty clay, which appeared partly disturbed because of piling displacement. Initial readings were taken August 10, 1944.

(b) At the future south lane location it was possible to attach the complete strain gage assembly to the four selected reinforcing bars prior to their installation in the mat. When the steel reinforcing mat was being assembled the four bars were then carried and tied-in to their selected positions. The compensating gage unit was centered and secured in place between the top and bottom bars. The soil pressure cells were placed as planned with the moveable piston resting on the clay soil. These cells were well seated into the soil and backed up by packing concrete on top of each one during the pouring of the sub-base.

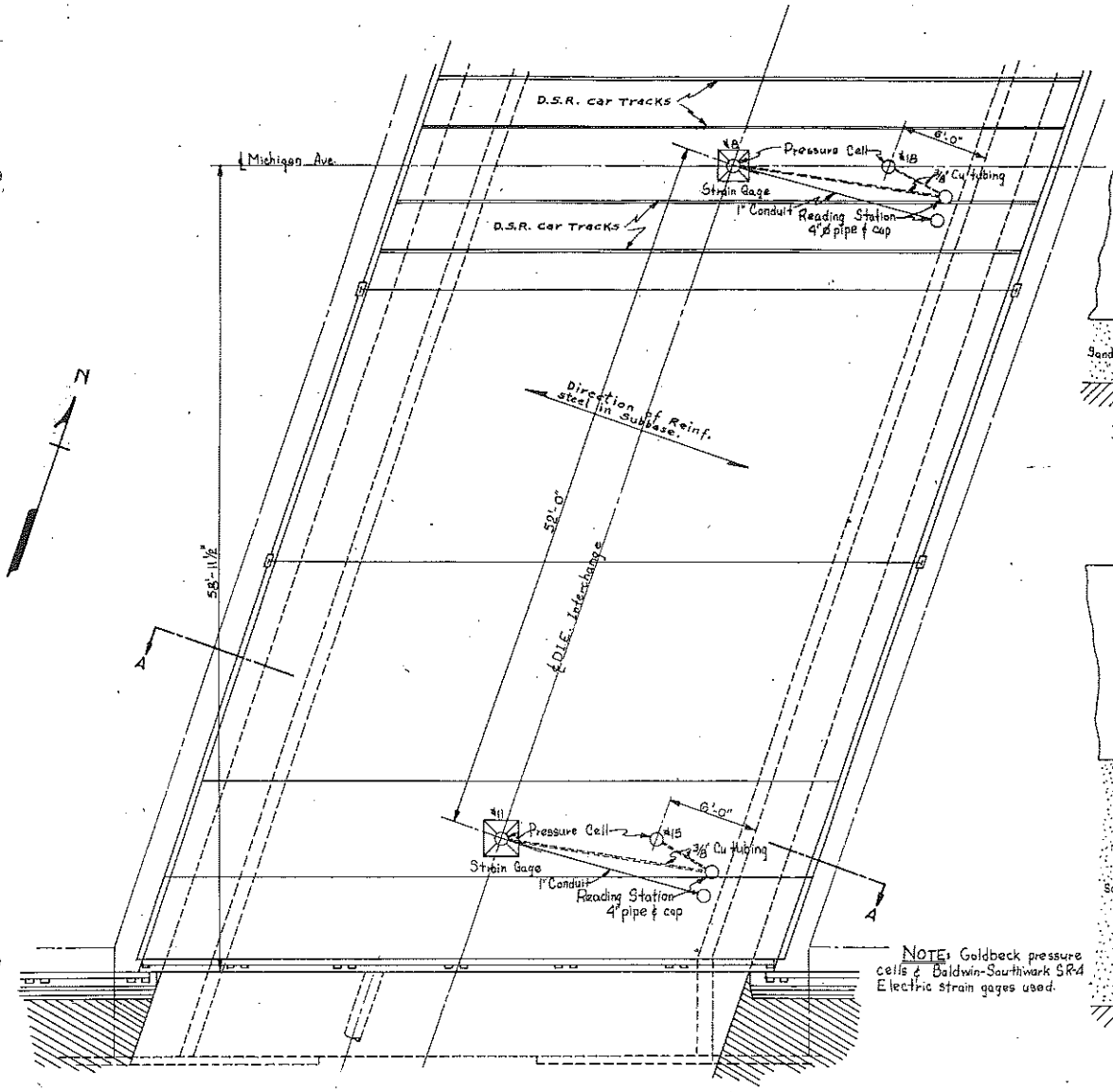
Notes describing the soil at each cell location are as follows: Cell #6 was placed on firm silty blue clay. Cell #7 was placed on a very spongy blue clayey silt. Cell #4 was placed on horizontal planes of firm clayey silt. It was apparent that some disturbance of the soil at this elevation had developed due mostly to pile driving which caused some displacement in an upward direction. See Plate #8 for details of strain gage and pressure cell installations.

Inspection of the pressure cell and strain gage installations was carefully conducted during the pouring of the sub-base slab to assure their proper functioning. The slab was poured by dropping concrete batches from the paving mixer from an average height of 5 feet, this seemed to pre-strain the reinforcing steel mat. During the initial setting period of the concrete, the first pressure cell and strain gage readings were recorded.

Available construction photographs showing foundation work at this structure are shown in Part V.

3. The Michigan Avenue Interchange was the third structure selected for soil pressure study. One set of measuring equipment was located beneath the centerline of Michigan Avenue and the other set near the south edge of the structure. At each location one pressure cell and set of strain gages was placed in the center of the sub-base span, also at each location one pressure cell was placed near the east abutment footing. Plate #9 shows installation details.

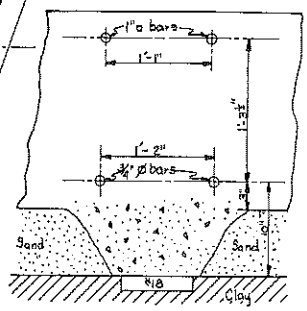
(a) Strain gages were attached, sealed and wired to the selected reinforcing bars which were subsequently carried by hand and placed in the reinforcing steel mat during the assembly. Connecting wires from the strain gages to the reading stations were protected by one-inch electric conduit pipes. The completed reinforcing steel mat assembly appeared to have a crown of about 4 to 6 inches in the center. This condition introduced initial strains in the test bars. Because of construction activity no reliable readings of the strain condition of the test bars were taken until they were embedded in concrete.



NOTE: Goldbeck pressure cells & Baldwin-Southwark SR4 Electric strain gages used.

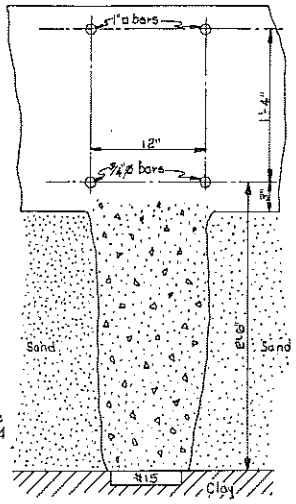
PLAN

Scale



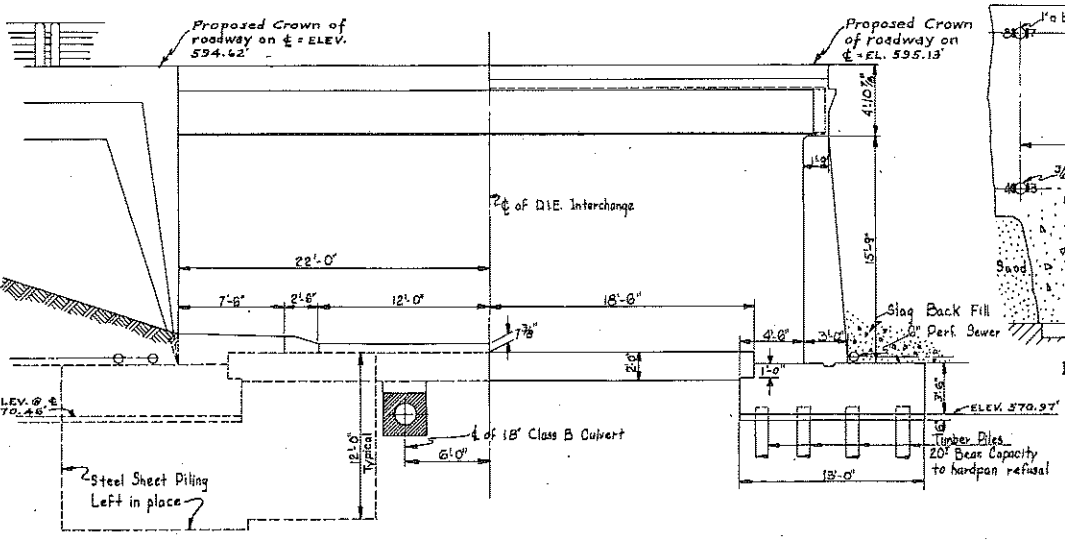
Installation of Pressure Cell #18
View Toward Reading Station

Scale



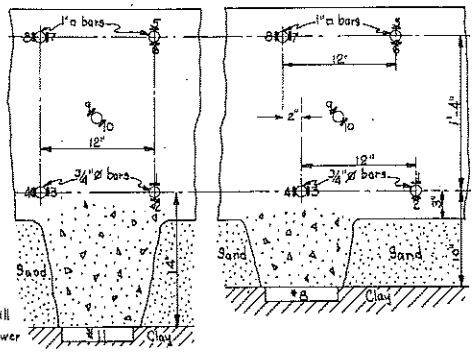
Installation of Pressure Cell #15
View Toward Reading Station

Scale



SECTION A-A

Scale



Installations of Pressure Cells #11 & #8
With Strain Gages
View Toward Reading Station

Scale

DETAILS REVISED APRIL 20, 1945.

MICHIGAN AVE. D.I.E. INTERCHANGE

Strain Gage & Pressure Cell
Installation Details

Project B-13 of 82-22-10

Installation Completed September 18, 1944

Drawn by SRJ

PLATE #9

(b) The soil pressure cells were placed at various elevations below the sub-base slab to assure being well seated in the smooth soft blue clay. This soil may be considered partially disturbed because of pile driving. It is estimated that the upward displacement between abutments due to pile driving amounted to about 2 feet. Other construction items that may influence the soil pressure study are: The disturbance caused by placing an 18-inch encased sewer near and parallel to the west abutment footing, and the effect of the unconsolidated backfill, about 4 feet wide, adjacent to the abutment footings. These were important especially because of the short sub-base span.

Photographs showing pressure cells, strain gage installation and foundation work for this structure are shown in Part V of this report.

PART IV

GENERAL CONCLUSIONS AND REMARKS

The pressure cells and the strain gages have been read at approximately one month intervals. It is planned to continue this procedure.

Drawings have been prepared showing in detail the installation of measuring equipment at the three structures.

The data collected during the first 10 months have been prepared in chart form to show graphically the soil pressures and internal stresses in the sub-base slabs. The soil pressures are shown in pounds per square foot and the strain gage results indicate stress in the reinforcing bars in pounds per square inch. This is based on actual tests showing that the modulus of elasticity of the steel is approximately 30,000,000 pounds per square inch.

All pressure cells seem to be functioning satisfactorily. One pressure cell was lost, its reading station was destroyed at the P.M.R.R. structure.

A total of forty strain gages were attached to the reinforcing bars. To date two strain gages are dead (broken electric circuit) and eleven gages are beyond the reading range of the Indicator (Strain Meter). This does not always mean that the steel bar has undergone a large change in stress since its initial reading. When a strain gage is attached to an unstressed bar its electrical resistance cannot be adjusted to zero but must be taken as registered on the Indicator. This initial resistance of the strain gage is

usually within the range of the Indicator. From this initial point introduced compression stresses decreases the resistance of the gage and introduced tension stresses increases the resistance of the gage. Refer to Plates #5 and #6 for a comparison between the mechanical and the electric strain gages in a tension check test.

Because of the complex results obtained from the strain gages during the first 10 months of this research project, it is recommended that some strain gage investigation be conducted in the laboratory. It is suggested that a few small concrete beams be constructed to investigate embedded strain gages. Later perhaps a prototype of the sub-base slab can be investigated. No doubt such a laboratory study would aid in the interpretation of the results so far obtained.

An important phase of this investigation is elevation records of the sub-base slabs. Limited records were kept during the construction period. Recently it was decided to set permanent reference points to ascertain the amount and direction of any movement in the sub-base slabs.

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3. "Five Years' Improvement of the Elastic Wire Strain Meters" - R. W. Carlson, Engineering News-Record, May 16, 1935.

4. "Application of Electric Strain Gages to Shipbuilding Problems" - A. R. Anderson and C. R. Nevitt, Baldwin Locomotive Works Bulletin 174.

   "Airframe Stress Analysis by the Electric Strain Gage" - W. T. Thompson, Aero-Digest, May, 1943.

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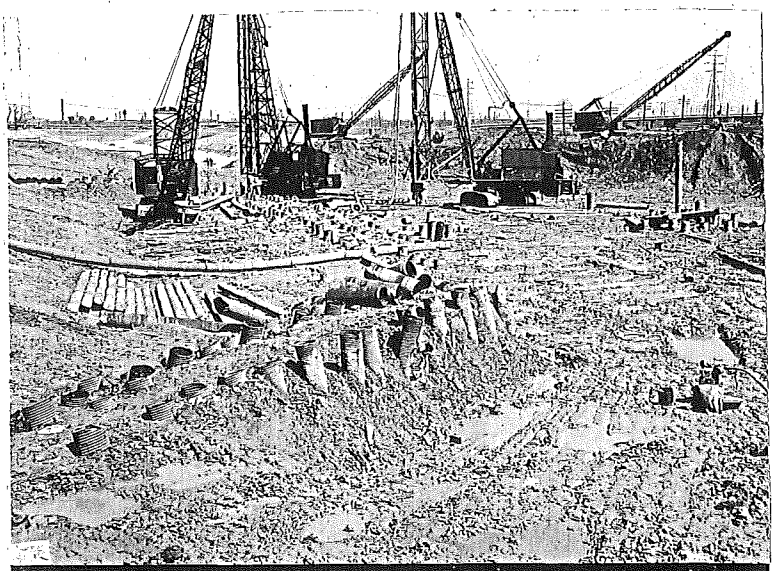
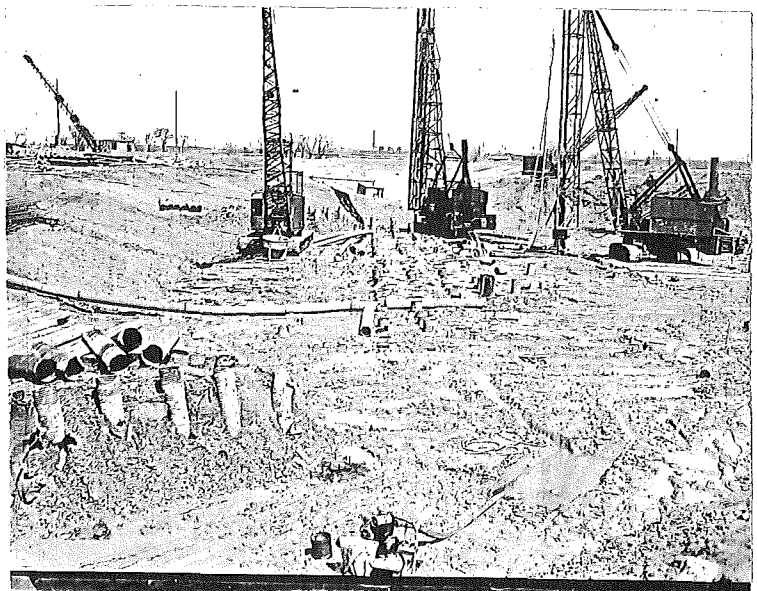
6. "A Rubber Housing for Waterproofing the Bonded-Wire Strain Gage" - Douglas McHenry, A.S.T.M. Bulletin, March, 1945.



No.166 Looking N.E. showing piling for the West abutment and wing walls - driven from a partial excavation.
X4 of 82-22-10 (JLB-4/12/44)

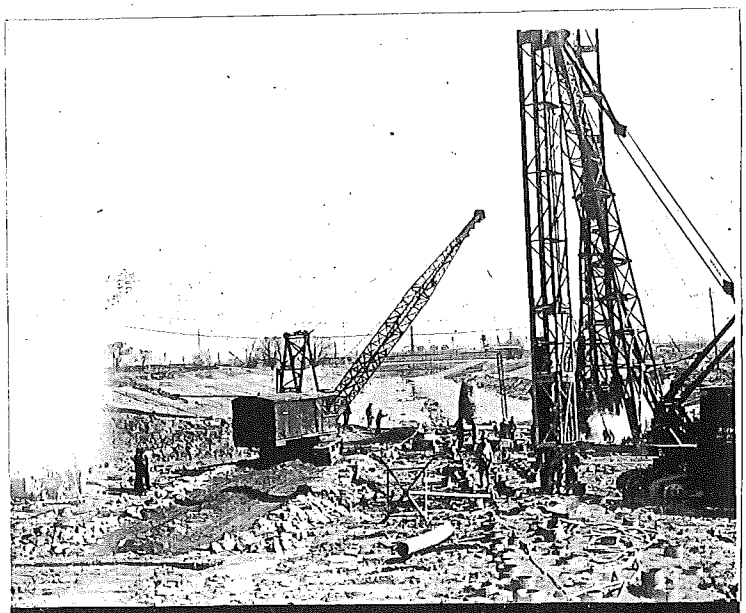


.167 Looking N.E. showing piling for the est abutment and wing walls - driven from a partial excavation.
4 of 82-22-10 (JLB-4/12/44)

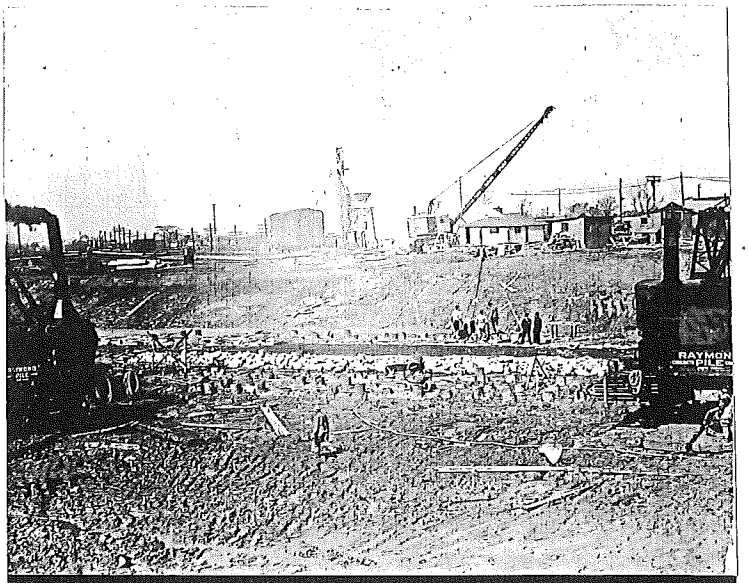
No.168 Looking West showing the South wing wal
piles of the East abutment & general view cent
pier & West abutment piles, partial excavation.
X4 of 82-22-10 (JLB-4/12/44)

No.169 Looking West showing close up of the
South wing wall piles of the East abutment, par-
tial excavation.
X4 of 82-22-10 (JLB-4/12/44)

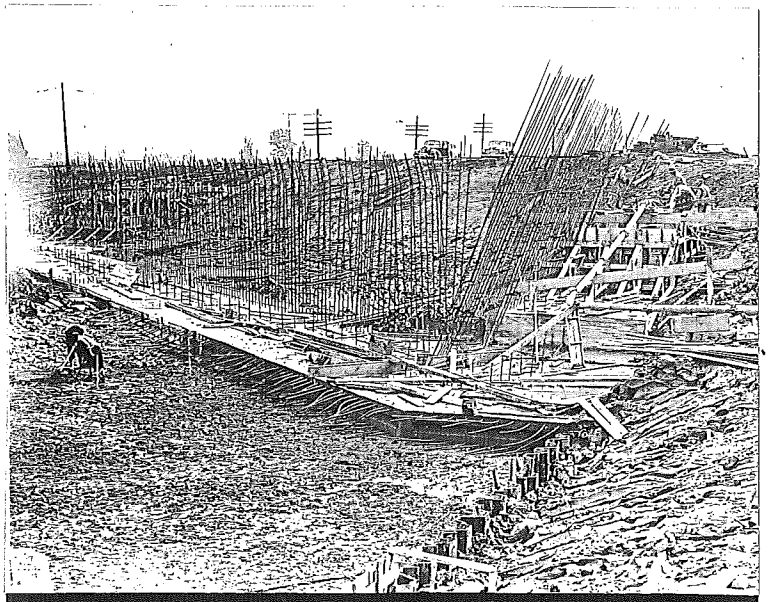
No.170 Looking S.W. showing N.Y.C.R.R.tracks re
location between Rotunda Drive Separation and
the N.Y.C.R.R. Bridge.
X4 of 82-22-10 (JLB-4/12/44)



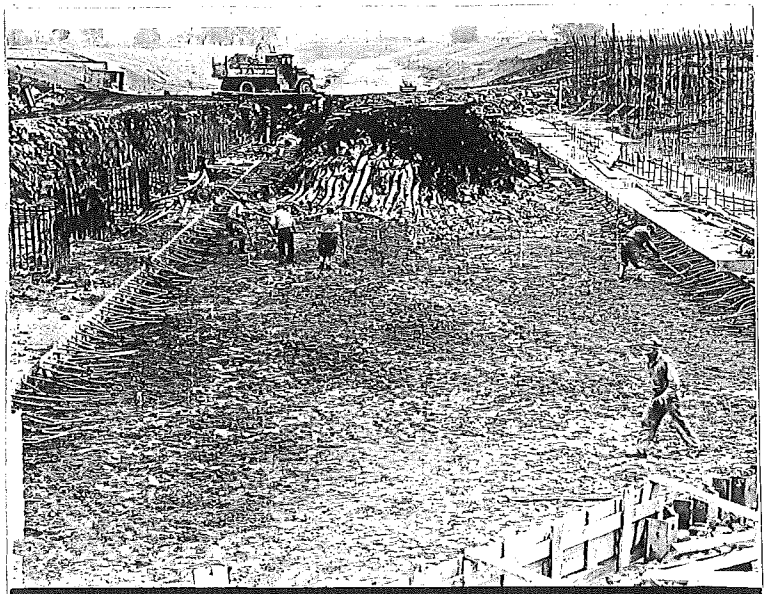
No.174 Looking Northeast - Showing pile driv
in center pier from partial excavation.
N.Y.C.R.R. - D.I.E. Structure.
X4 of 82-22-10 (JLB-4-27-44)



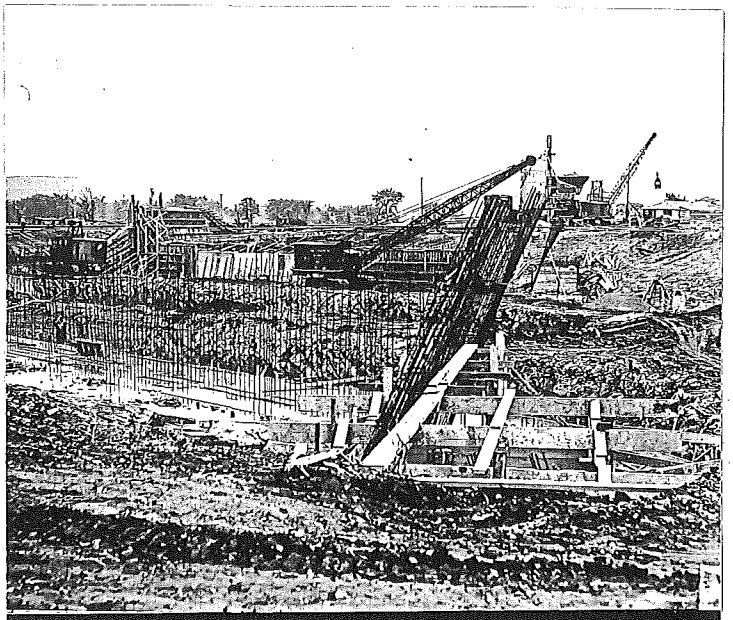
No.175 Looking West - Showing foundation wor
on N.Y.C.R.R. - D.I.E. Structure.
X4 of 82-22-10 (GOK 4-27-44)



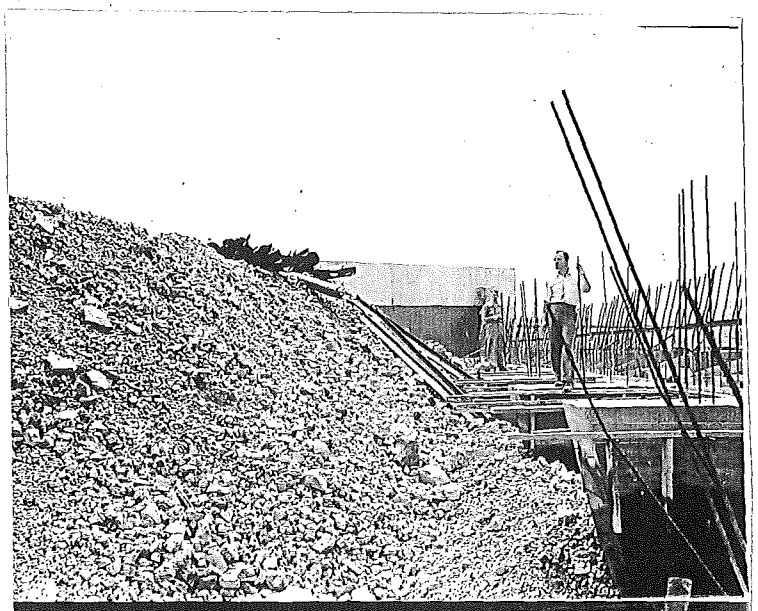
No. 198 Looking East - Showing south end of
east abutment - D.I.E.-N.Y.C.R.R. Crossing.
X4 of 82-22-10 (LEW 6-3-44)



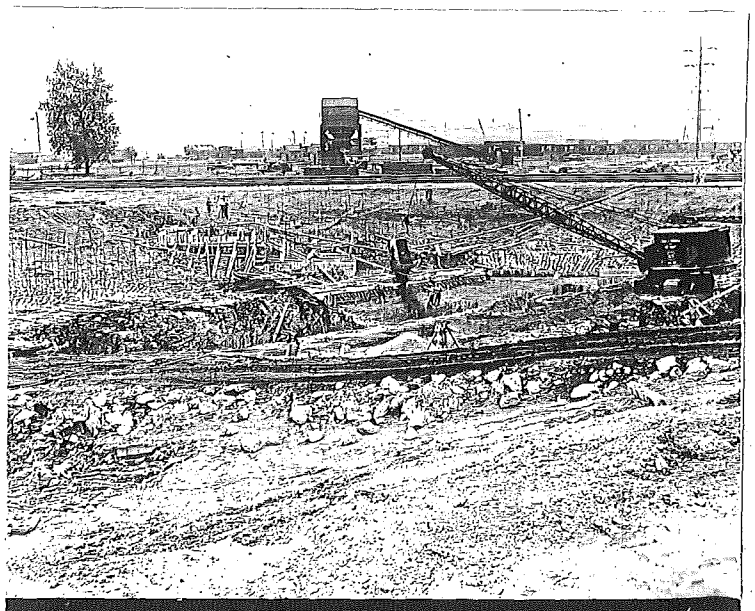
No. 199 Looking Northeast - Showing sand sub-base for 24" sub-base reinforced slab between center pier and east abutment.
X4 of 82-22-10. D.I.E.-N.Y.C.R.R. (LEW 6-3-44)



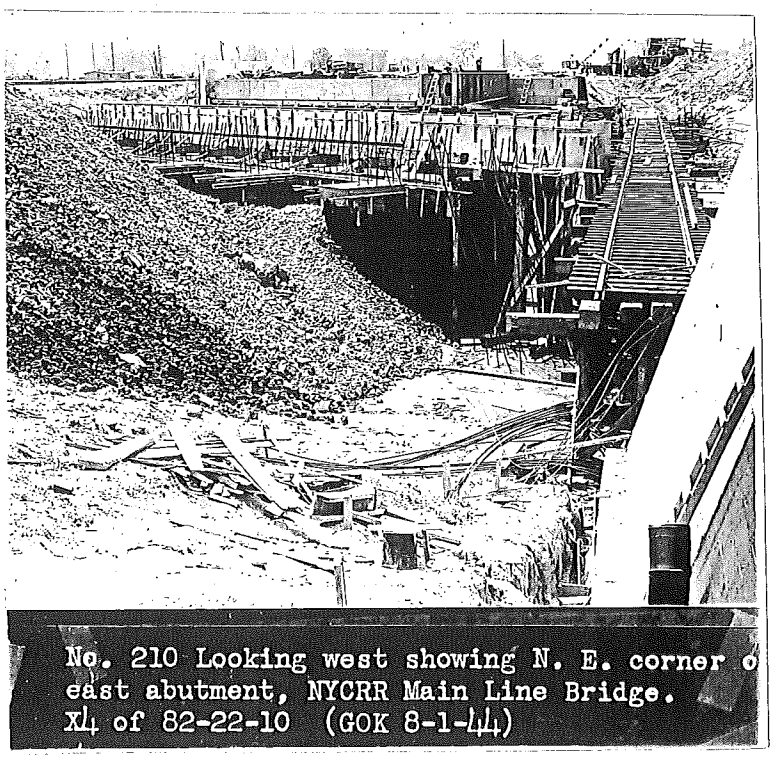
No. 200 Looking West - Showing view of construction at D.I.E. - N.Y.C.R.R. Crossing.
X4 of 82-22-10 (LEW 6-3-44)

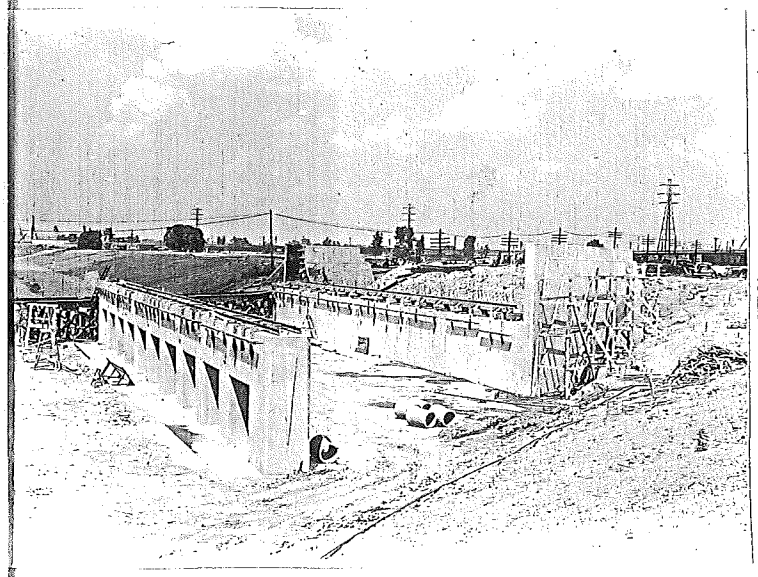


No.209 Looking south, view of slag fill at east abutment, NYCRR Main Line Bridge. X4 of 82-22-10 (GOK 8-1-44)

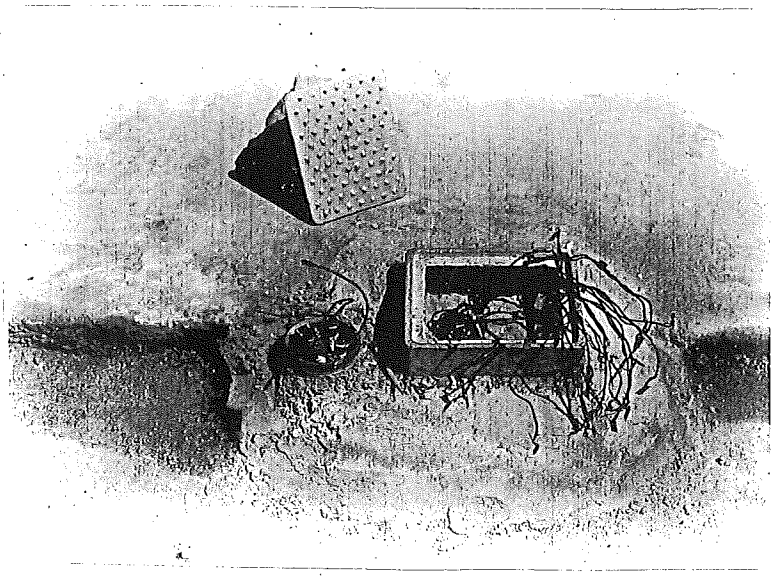


o. 201 Looking South - Showing over-all vi of construction at D.I.E.-N.Y.C.R.R. Crossin X4 of 82-22-10 (LEW 6-3-44)

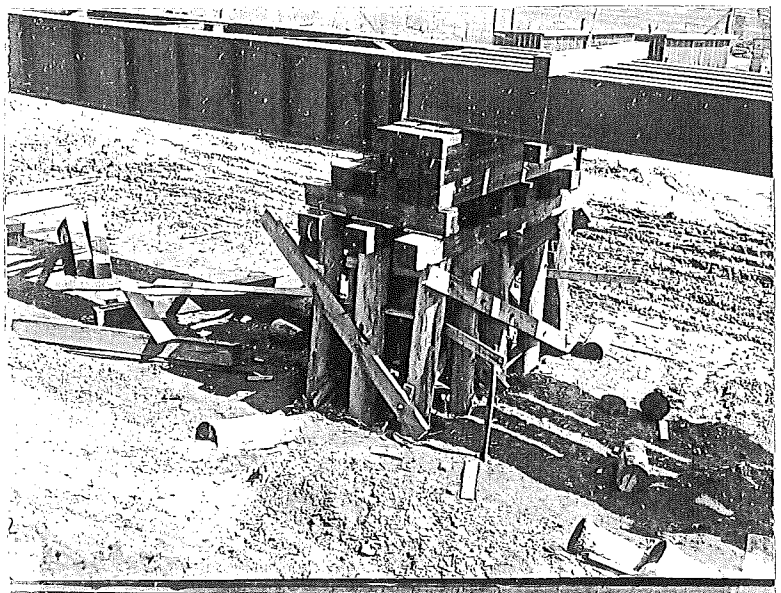




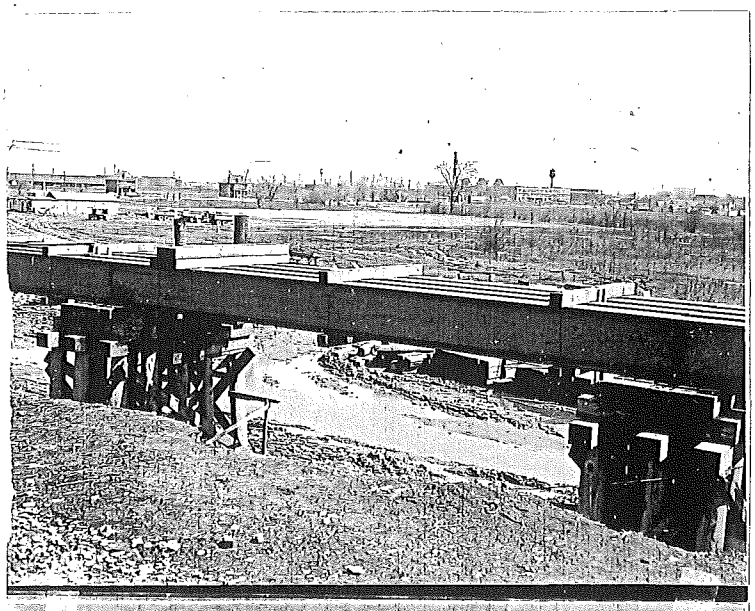
Looking N.E.
N.Y.C.R.R. Main Line Bridge
(E.F.) July, 1945



Close-up of Reading Station
Near East Abutment
(E.F.) July, 1945

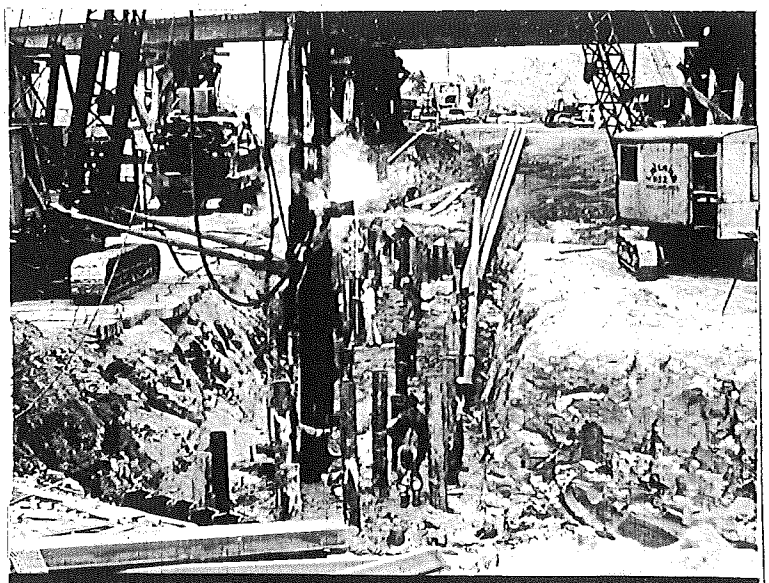


No.162 Looking East, showing close up of pile bent of the East P.M.R.R. track relocation during Bridge Construction.
X7 of 82-22-10 (JLB 4/12/44)

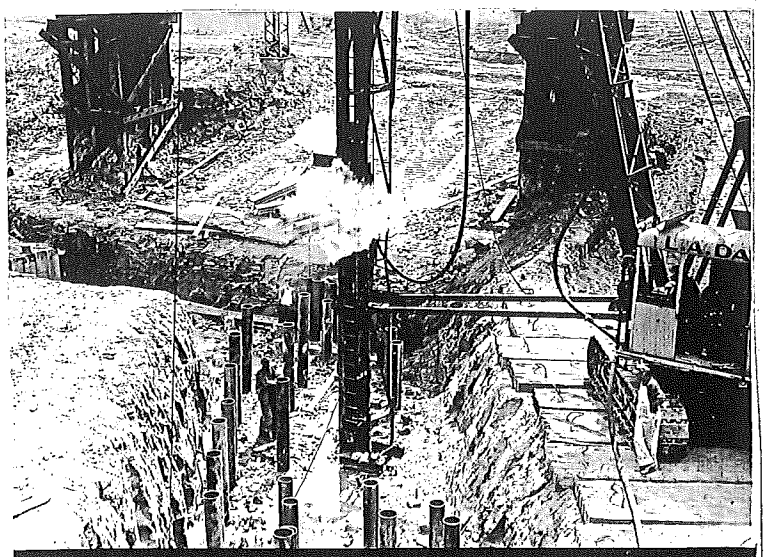


No.163 Looking N.E. on D.I.B. centerline, showing Northbound P.M.R.R. track relocation and general view towards Michigan Avenue.
X7 of 82-22-10 (JLB 4/12/44)

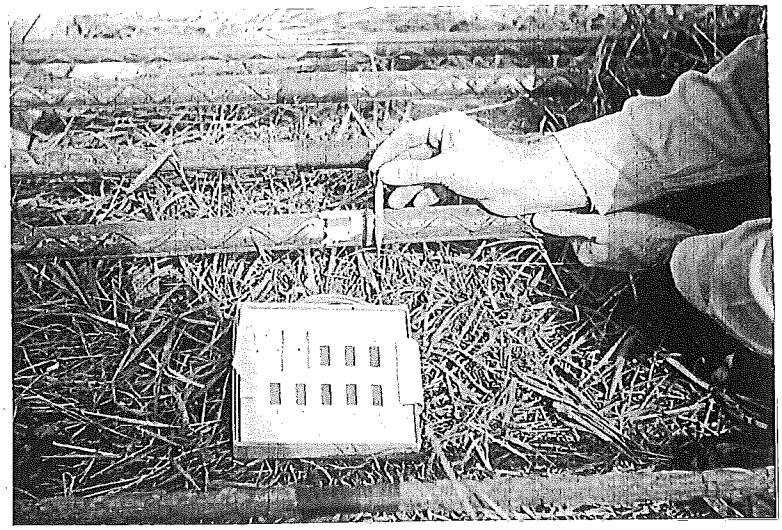
P.M.R.R. - MAIN LINE BRIDGE CONSTRUCTION



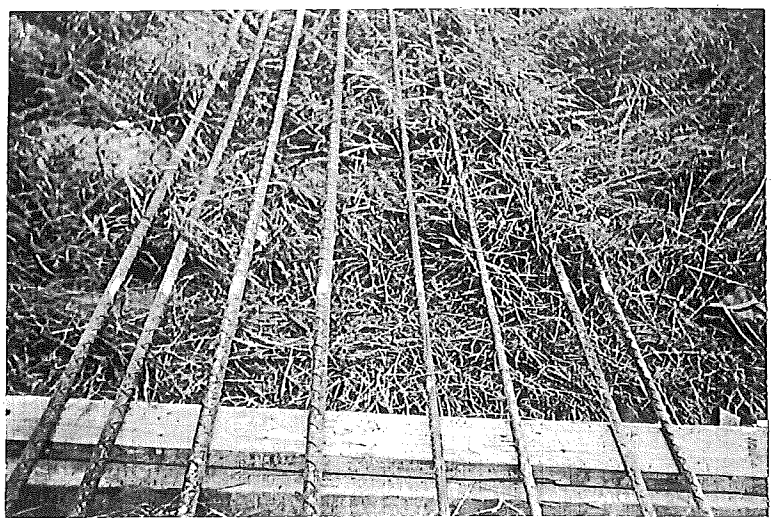
No.211 Looking N. E. showing pile driving at south abutment of P.M.R.R. Bridge. X7 of 82-22-10 (GOK 8-1-44)



No. 213 Looking west showing pile driving at south abutment of P.M.R.R. Bridge. X7 of 82-22-10 (GOK 8-1-44)



NO. 4 44 E-10
CLOSE-UP OF STRAIN GAGES ATTACHED TO STEEL BARS
B 13 of 82-22-10
(L.D.C. 9-15-45)



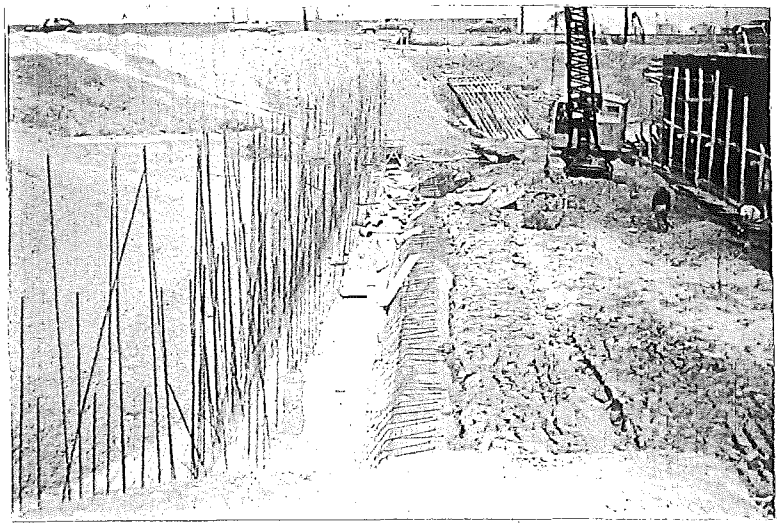
NO. 5. 44 E-10
STRAIN GAGES ATTACHED TO STEEL BARS
B 13 of 82-22-10
(L.D.C. 9-15-45)

MICHIGAN AVENUE - D.I.E. INTERCHANGE

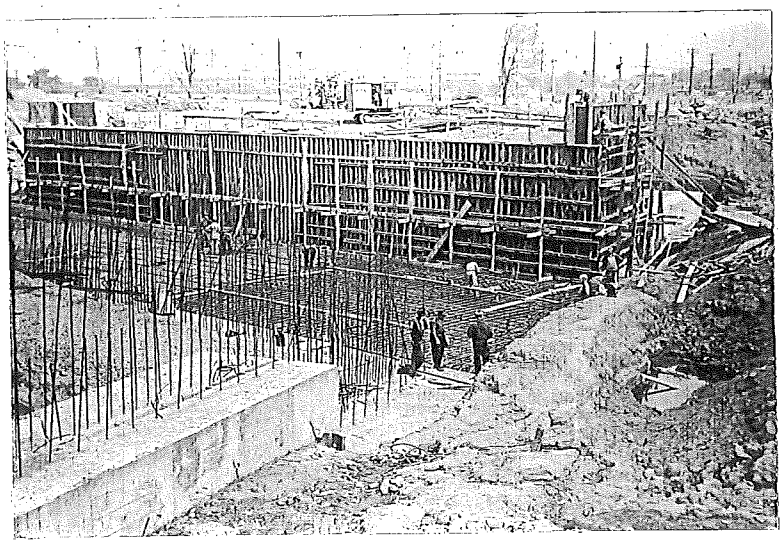
NO. 12. 44 E-10
LOOKING SOUTH - SHOWING SUBGRADE BEFORE TRIMMING
AND PLACING SAND SUB-BASE. NOTE ENCASED SEWER.
B 13 of 82-22-10 (L.C.D. 9-16-44)

NO. 10. 44 E-10
UNCOMPACTED CONDITIONS OF FILL UNDER
TIE BARS ADJACENT TO ABUTMENT FOOTINGS.
B 13 of 82-22-10 (L.D.C. 9-16-44)

MICHIGAN AVENUE - D.I.E. INTERCHANGE

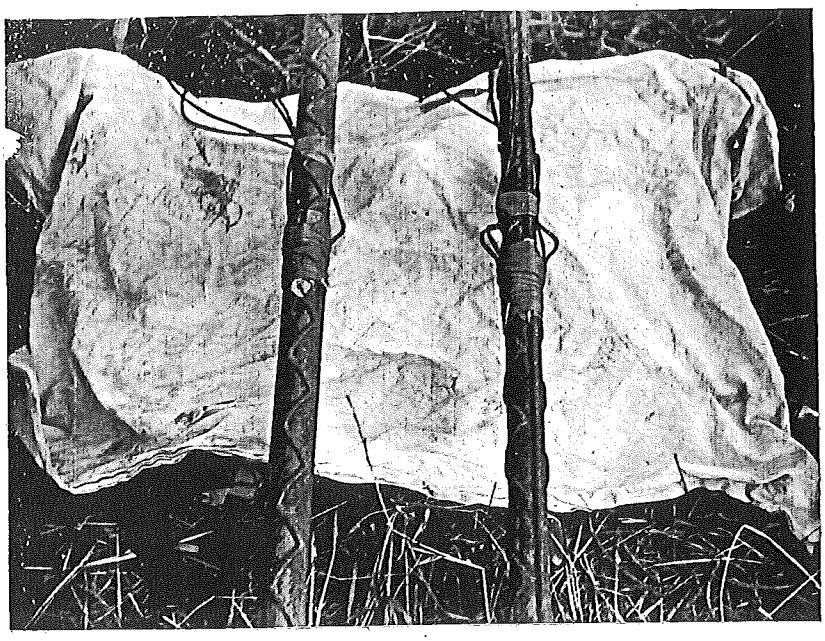


NO. . 44 E-10
LOOKING NORTH
FINAL CUT OF CLAY SUBGRADE
B 13 of 82-22-10 (L.D.C. 9-15-45)

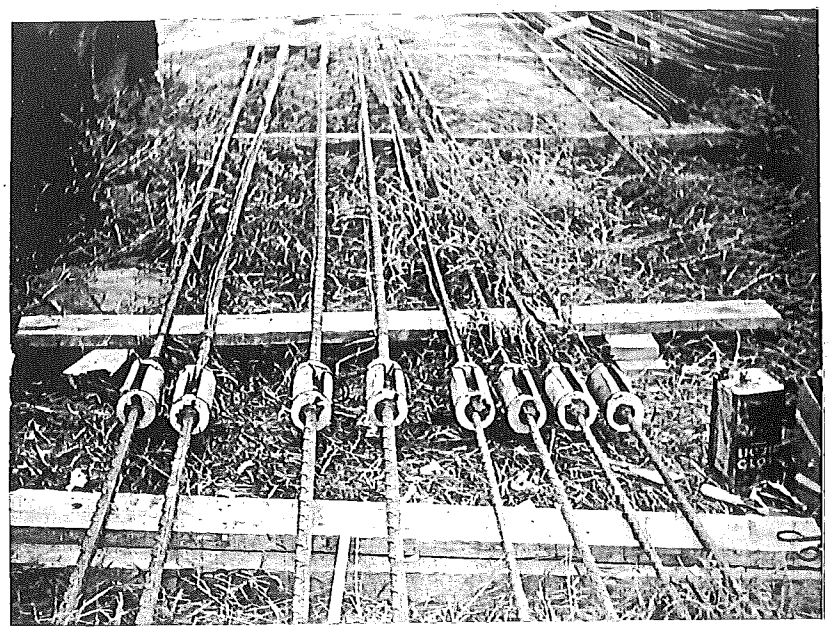


NO. 22. 44 E-10
LOOKING NORTHEAST. GENERAL VIEW OF PROGRESS
SHOWING STEEL BEING PLACED FOR SUB-BASE SLAB
B 13 of 82-22-10 (L.D.C. 9-16-44)

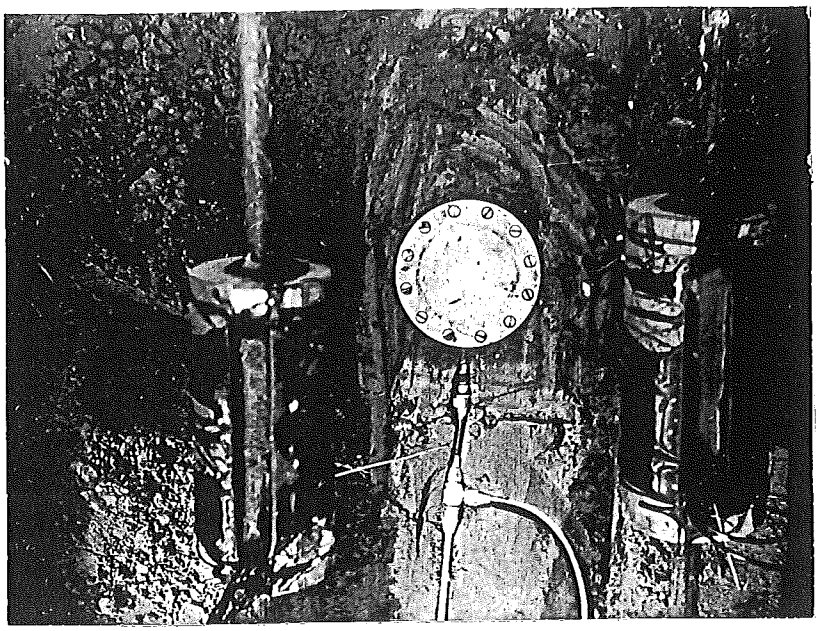
MICHIGAN AVENUE - D.I.E. INTERCHANGE



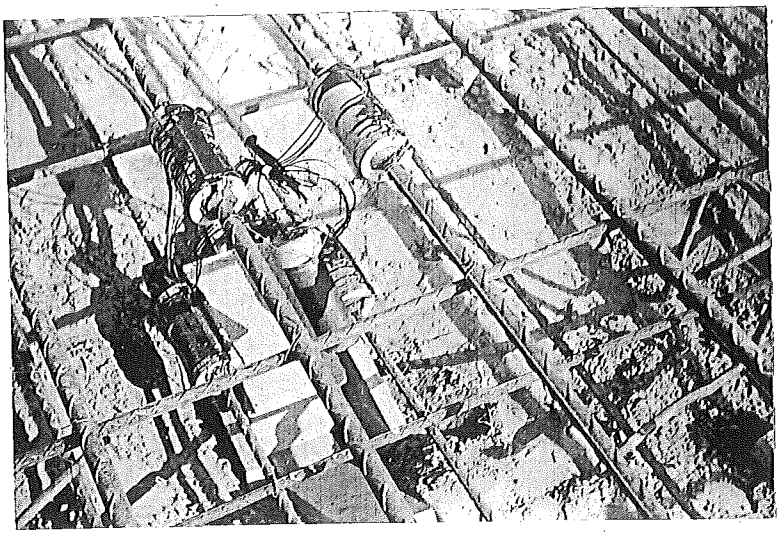
NO. 14 44 E-10
CLOSE-UP OF REINFORCING BARS SHOWING TAPE
OVER GAGES AND WIRE LEADS ATTACHED
B 13 of 82-22-10
(L.D.C. 9-16-44)



NO. 15 44 E-10
METAL SLEEVES ATTACHED TO BARS
TO CONTAIN MOISTURE-PROOFING MATERIAL
B 13 of 82-22-10
(L.D.C. 9-16-44)

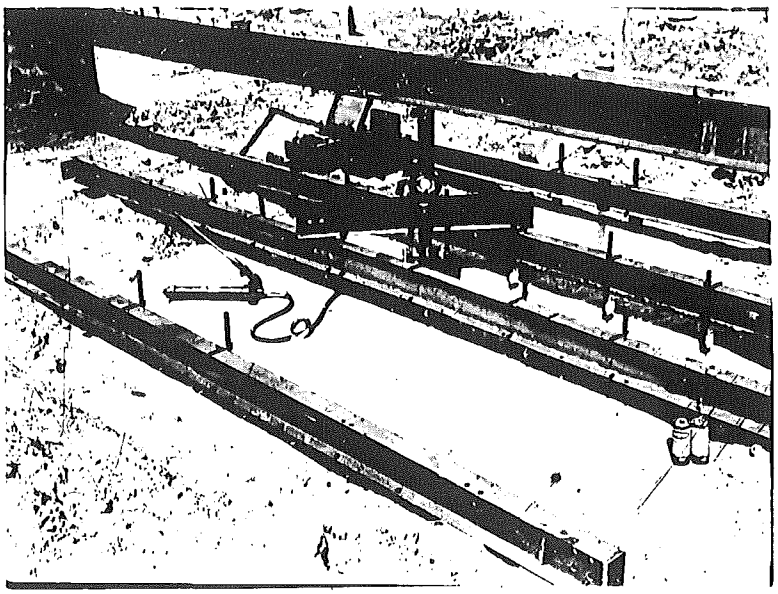


NO. 20. 44 E-10
CLOSE-UP OF GOLDBECK CELL #11 AND STRAIN GAGE SLEEVES
ON SOUTH SIDE OF MICHIGAN AVENUE AND CENTERLINE OF
D.I.E. INTERCHANGE. NOTE WOA ASPHALT IN GAGE SLEEVES.
B 13 of 82-22-10 (L.D.C. 9-16-44)

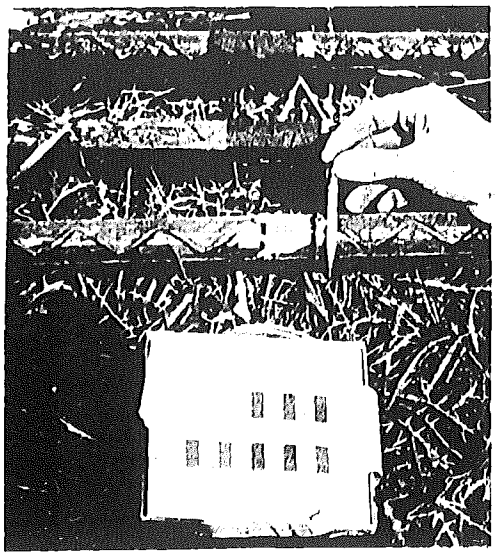


No. 26 44 E-10
STRAIN GAGE INSTALLATION OVER PRESSURE CELL #11.
NOTE DUMMY GAGE. CEMENT BLOCK AND WOOD
REMOVED BEFORE SLAB IS POURED.
B 13 of 82-22-10 (L.D.C. 9-16-44)

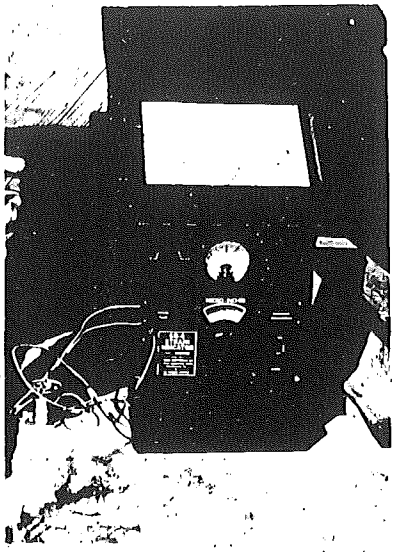
MICHIGAN AVENUE - D.I.E. INTERCHANGE



SUBGRADE REACTION STUDY. METHOD OF LOADING CONCRETE SLAB.



Electric Strain Gage on Reinforcement Bar



Electric Strain Indicator

DETERMINATION OF SOIL PRESSURE AGAINST GRADE SEPARATION STRUCTURES
DETROIT INDUSTRIAL EXPRESSWAY