sampling and testing have an important bearing on the degree of disturbance associated with these operations.

4) Where test pits cannot be utilized for securing undisturbed samples, thin walled sampling spoons of the open or piston type are the best equipment presently available for this purpose.

5) Visual evidence of soil disturbance may be demonstrated by cutting thin sections from the samples and allowing them to dry under atmospheric conditions.

6) A small disturbance due to sampling and testing operations may have an appreciable effect on the reliability of the laboratory test results.

7) The applicability of analytical solutions to foundation problems depends, to a large degree, on the reliability of the laboratory test results used therein.

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SUB-SECTION III c

MEASUREMENTS OF PRESSURES AND DEFORMATIONS

III c 6

INSTRUMENTATION FOR FIELD MEASUREMENTS OF DEFLECTIONS AND PRESSURES FOR AIRPORT PAVEMENTS

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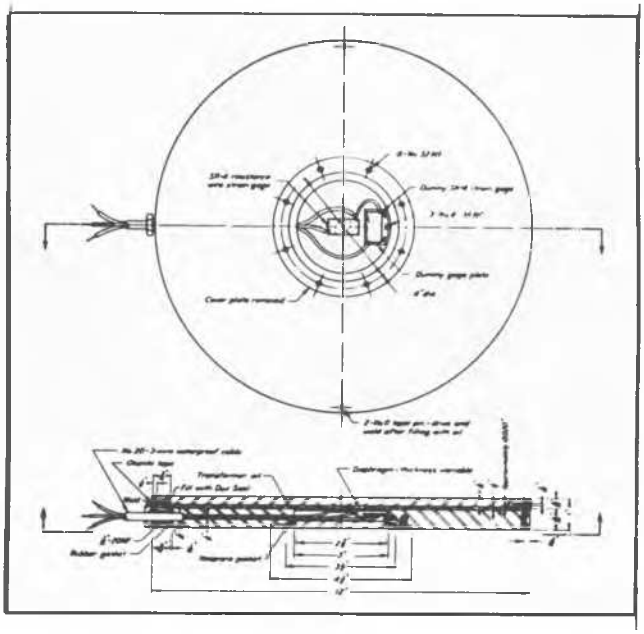
SYNOPSIS

This paper describes operation and installation of one type of earth pressure cell and two types of deflection gages used by the Waterways Experiment Station in measuring stresses and strains in flexible pavement structures under standing and moving wheel loads and under plate-bearing loads. Also contained in this paper is a brief description of installations in three test sections utilizing these pressure cells and deflection gages.

The Flexible Pavement Branch of the Waterways Experiment Station was established by the Corps of Engineers during the early part of World War II to conduct research on the design of flexible type pavement. A part of the research conducted by this Branch has involved the measurement and study of stresses and strains induced in bases and subgrades beneath flexible pavements. This paper is confined to the mechanics and installation of pressure cells and deflection gages developed by the Instrumentation Branch of the Experiment Station as used in three experimental test sections: Flexible Pavement Tests, Marietta, Georgia; Stress Distribution Test Section, Waterways Experiment Station; and Stockton No. 2 Test Section. In these first two test sections all pressure cells and deflection gages were designed and constructed by the Experiment Station, while in the Stockton No. 2 Test Section pressure cells only were by the Experiment Station.

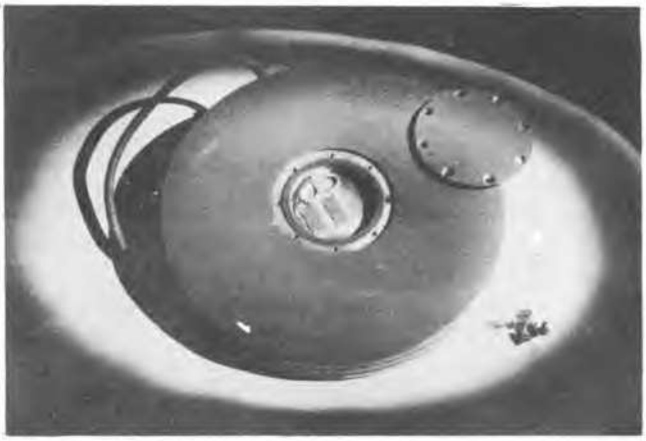
In all three of the above test sections, only one type of pressure cell was installed, and this is referred to hereinafter as the WES cell. The WES cell is used for measuring subsurface pressures under standing or moving loads. In the two test sections conducted by the Experiment Station, two basically different types of deflection gages have been used, one called the cantilever type gage and the other the selsyn motor gage. The selsyn gage is at present adapted to measurement of surface or subsurface deflections under standing loads only, while the cantilever gage is capable of measuring these deflections under both standing and moving loads.

The WES cell has been made in several



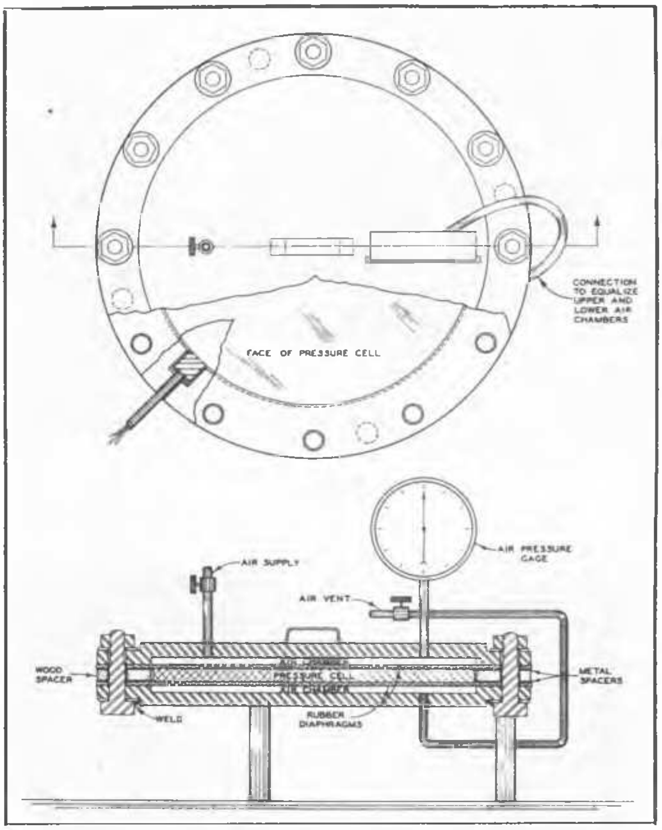
WES pressure cell

FIG. 1



Waterways Experiment Station 12 inch pressure cell

FIG. 2



Pressure cell calibrating chamber

FIG. 3

sizes during its development, but the ones primarily used in the test sections were of a 12-in. diameter and 1 in. in thickness. A plan and cross section of this cell are shown on figure 1, and a photographic view is shown on figure 2. The cell consists essentially of a machined steel diaphragm to which is attached a Baldwin-Southwark SR-4 resistance wire strain gage. In the simpler application where only short-time service is desired the strain gage is cemented to the diaphragm by ordinary Duco household cement. Where long-time service and gage stability are desired, the gage is cemented to the diaphragm with a bakelite compound which is cured by baking the cell in an oven at 175° F for one hour followed by a baking temperature of 250 °F for from two to three hours. A second (dummy) gage is installed on a portion of the pressure cell not subject to strain and serves to compensate for temperature changes. Pressure is transmitted from the soil through the face plate and oil-filled chamber to the diaphragm and induces a strain in the strain gage resulting in a change in resistance of the gage. This change in resistance may be measured in a Wheatstone bridge circuit and thus furnish a measure of applied pressure.

Prior to installation, the WES cells are placed in a pneumatic calibration chamber, details of which are shown on figure 3. In this chamber pressure is applied to the faces of the cell by means of rubber diaphragms, the unit air pressure being measured by a standard airpressure gage of the dial type. Increments of pressure are applied and resistance readings of the active strain gage are recorded for each increment. From these data a graph may then be plotted of applied unit pressure versus change in resistance. It has been determined by numerous such calibrations that for all practical purposes the variation of resistance with change of pressure plots a straight line on rectangular coordinate paper; thus, a single calibration factor may be obtained for each cell.

Considerable care is taken in the installation of these cells to insure that the soil placed around the cell duplicates, in so far as possible, the density of the remainder of the soil mass in which the cell is placed. In test section work the cells have all been placed in fills of selected materials. The fill is compacted to the desired density and moisture content to an elevation about a foot above that at which the cell is to be placed. Material is hand-excavated down to the cell elevation such that the excavation has relatively flat side slopes. A very thin layer of dry sand is used as a levelling course beneath the cell when placed horizontally. When placed vertically the soil is compacted manually on both sides of the cell. Compaction generally is accomplished by an air tamp, and frequent checks

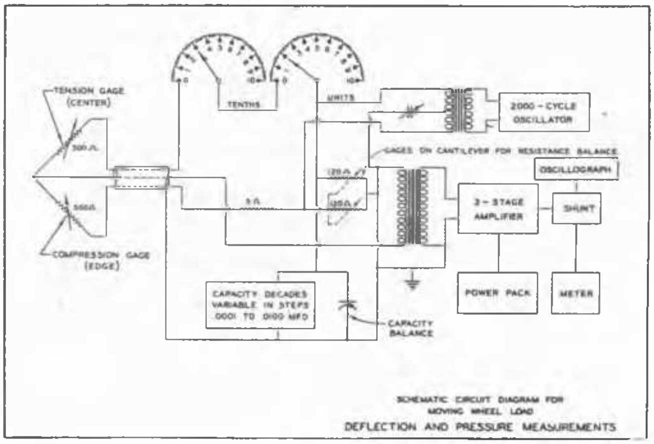
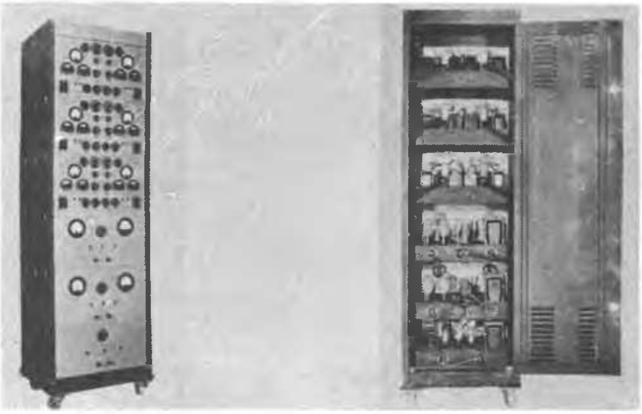
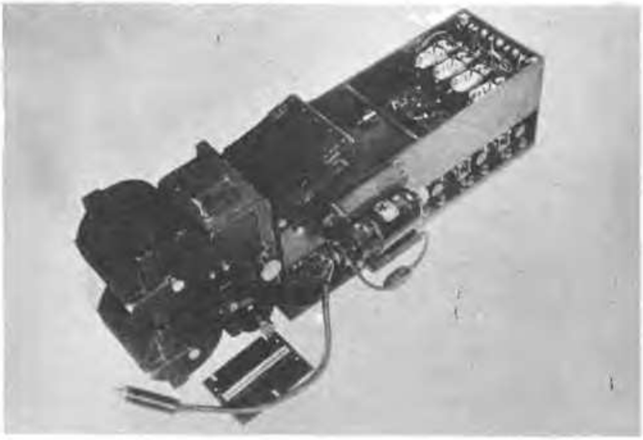


FIG. 4



Six channel amplifier for use with SR-4 strain gages.

FIG. 5



Westinghouse type PA portable 7 channel recording oscillograph

FIG. 6

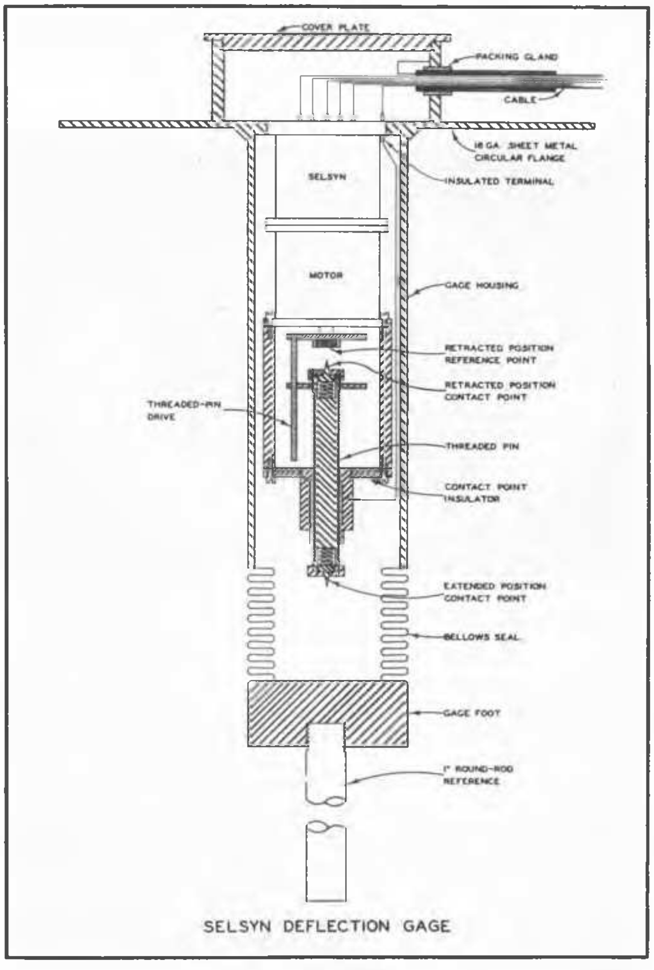
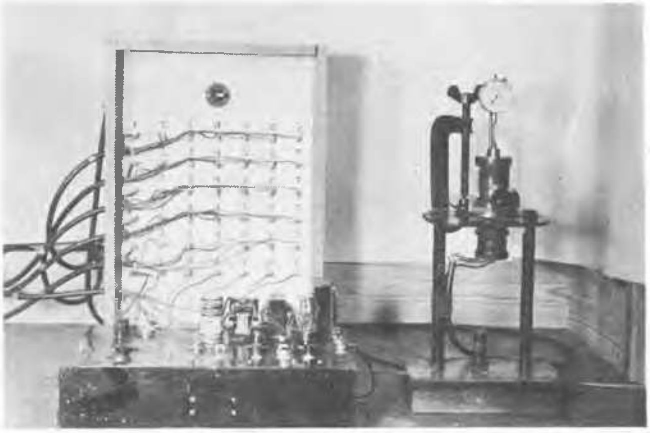


FIG. 7

are made with a small density sampler to insure proper density. Prior to cell placement, trial compaction in areas not to be tested has been found useful in perfecting compaction procedures such that a minimum of density tests around the cells was required.

Measurements of induced pressures are obtained either by a Wheatstone bridge or by means of a recording oscillograph depending on whether standing or moving loads are to be applied. When stresses are to be measured under standing wheel loads or under plate bearing loads the Wheatstone bridge may be connected directly to the cell and resistance readings obtained before and after the application of the load. The measured change in resistance may then be converted, by means of the calibration factor, to a measurement of induced pressure. Where pressures are to be measured under moving wheel loads it is necessary to employ a recording oscillograph and associated amplifying equipment. Present practice at the Experiment Station involves use of a 3-stage, low-frequency, carrier-modulated amplifier with signal rectification and filtering to give a direct-current trace on the oscillograph record linear with respect to bridge unbalance input. Figure 4 illustrates the schematic arrangement of the set-up for measurement of strain (resistance change) under moving or standing loads, including means for resistance and capacity balancing of the strain-gage bridge, 2.000-cycle oscillator supplying the bridge, resistance decades for calibrating purposes, the 3-stage amplifier and associated power supply, and means to observe the output current as supplied to the oscillograph. Figure 5 is a photograph of a six-channel amplifier of the type just described, containing a common oscillator and power supplies, whereby records from six pressure cells can be recorded by six



Selsyn measuring gage, contact signal indicator, and gage selector panel

FIG. 8

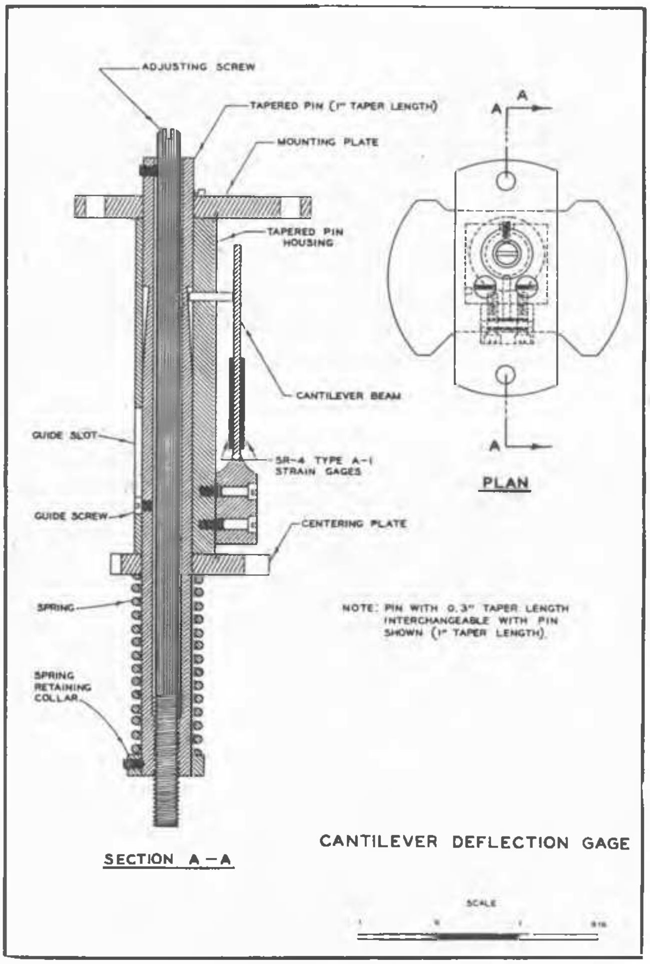


FIG. 9

Cantilever deflection gage

FIG. 10

elements of a recording oscillograph. Figure 6 is typical of the multielement recording oscillographs as used for this purpose.

A cross-sectional view of the selsyn deflection gage is shown on figure 7. This gage utilizes the fact that when a pair of selsyn motors is interconnected, a rotation of one of the motors results in an equal rotation of the other. This principle is utilized by attaching screw-thread mechanisms of equal pitch, or of known relative pitches, to the shafts of the motors such that each revolution of the motor drives the threaded pin inward or outward a known amount. Thus, the movement of the threaded pin on one of the motors can be determined by measuring the movement of the threaded pin of the other motor of the pair.

For the measurement of deflections under standing wheel loads or plate loads, one of the selsyn motors is imbedded shaft downward in the soil, properly housed by a waterproof container and attached to a circular sheet-metal flange as shown on figure 7. The sheet-metal flange fixes the unit into the surrounding soil and is considered to be the plane on which the deflection is measured. A stationary reference is installed about an inch beneath the threaded pin when the pin is in its retracted position. This reference generally consists of a 20-ft steel rod driven into the ground and capped with a 2-in. diameter smooth-surfaced steel head called the gage foot. The buried motor is coupled with one which is mounted in a rack as shown on figure 8. The motor is mounted into the rack in such a manner that its threaded pin contacts an Ames dial which measures pin movements to .001 in. An associated electrical contact is installed such that when the threaded pin of the buried motor contacts the stationary reference or gage foot an electrical circuit is completed which causes a buzzer signal to sound. A similar circuit is completed and sound signal received when the threaded pin of the buried motor is in its completely retracted position. Thus, this gage may be considered as a micrometer operated by remote control.

Prior to load application the distance is measured from the retracted position of the buried gage to the position at which the threaded pin contacts the reference. The gage is then returned to the retracted position and the load applied. A second measurement is taken to the reference in a similar manner, the difference in the two measurements being a measure of deflection caused by the load.

A plan and cross-sectional view of the cantilever type deflection gage is shown on figure 9, and a photographic view of the gage assembled and unassembled is shown on figure 10. By reference to these figures it may be seen that the cantilever gage operates in the following manner. A hollow cylindrical shaft (tapered pin) is tapered to a constant slope

Cantilever deflection gage calibration rack

FIG. 11

over a part of its length. This tapered pin contains an adjusting screw which effectively allows the tapered pin to be placed in contact with a fixed reference. Movement of the tapered pin housing with respect to the tapered pin causes bending of the cantilever beam mounted on the side of the housing by means of a small pin extending through the side of the housing and riding on the taper. Two strain gages are cemented to the sides of the cantilever beam as shown on figure 9. Bending of the cantilever beam causes a change in the resistance of these two strain gages which are connected in a Wheatstone bridge circuit such that this resistance change is additive for the two strain gages. A coiled spring attached to the tapered pin causes it to return to its original position after movement has been induced.

Prior to installation in the test section each gage is placed in a calibration rack as shown on figure 11. By placing the bottom of the tapered pin on an adjustable gage foot and by placing an Ames dial in contact with the upper end of the tapered pin, the tapered pin may be moved in known increments. The gage is calibrated by measuring resistance change over a range of measured deflections. As noted for the pressure cells, a linear variation of deflection with resistance change is generally obtained and a single calibration factor can thus be obtained for the gage. Gage calibrations are checked frequently during the period of testing to insure continued accuracy.

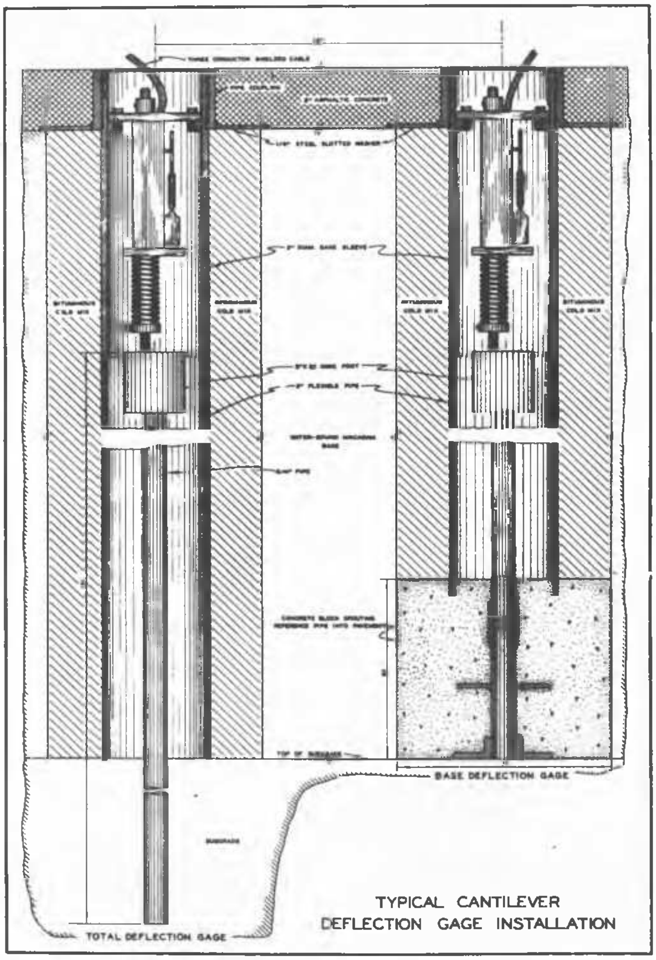


FIG. 12

The cantilever type deflection gage is generally installed in a dual arrangement as shown on figure 12, utilizing a similar type stationary reference as required previously for the selsyn gage. The gage is bolted into a pipe sleeve containing a circular flange for bonding the sleeve into the pavement or surrounding soils as shown. As indicated on figure 12, this type of dual arrangement furnishes a measurement of both the total surface deflection and of compression within the base, the difference between the two being a measure of the deflection of the surface of the subgrade.

Movement of the cantilever gage may be measured beneath standing wheel loads or plate bearing loads by the Wheatstone bridge; however, moving wheel loads require recording oscillographs and associated amplifying equipment as described previously for the pressure cells. Where measurements under standing loads are described for periods exceeding about 5 minutes the selsyn gage is preferable because of slight drifting over a period of time in the electrical measurement circuits of the cantilever type gage.

Pressure and deflection measurements by Waterways Experiment Station instrumentation to date are almost entirely measurements of induced stresses and strains resulting from the application of moving or stationary loadings. The present WES cells and the cantilever gages are considered to be unsatisfactory for the measurement of pressures and deflections over a long period of time; however, it is considered that the selsyn type deflection gage adequately measures settlements over a period of time.

The flexible pavement test section at Marietta, Georgia, contained two groups each of four pressure cells. One group of cells was installed at various depths in a clay subgrade beneath a macadam base and asphaltic concrete pavement while the other group was placed similarly in a sand subgrade beneath a sand asphalt pavement. Deflection gage installations similar to that illustrated on figure 12 were made in triplicate in three macadam base pavements of different base thickness and in a sand-clay base item. These installations were for the purpose of obtaining deflections at the surface of the pavement and of the surface of the subgrade. Single deflection gage installations, to measure pavement surface deflections only, were made in triplicate in a pavement containing a telford base. Measurements of pressures and deflections were made beneath moving and standing wheel loads of B-24 and B-29 planes at three different wheel loads and with plane motors dead and running. A detailed report on this project is available as a part of the report entitled "Certain Requirements for Flexible Pavement Design for B-29 Planes" published by the Waterways Experiment Station.

Deflections and pressures are being measured by the Waterways Experiment Station at several depths in a test section beneath loads applied by flexible faced loading plates to simulate tire loadings. These tests are in progress at the time of writing of this paper, and it is contemplated that another paper entitled "Stresses and Displacements in a Homogeneous Soil" by W.J. Turnbull and S.M. Fergus will be presented at this conference describing them in greater detail. The selsyn type deflection gage is used to determine vertical deflection profiles beneath single and dual plate systems of several load magnitudes and different dual spacings representing hypothetical single and dual wheel plane loadings. WES cells were installed in horizontal, vertical and 45-degree positions to measure induced stresses on these planes under the previously-described conditions. This test section was constructed of a uniform clayey silt soil throughout for the purpose of furnishing stress-strain data in as nearly a homogeneous soil mass as it was practicable to construct.

WES pressure cells were installed in vertical, horizontal, and 45-degree positions in the Stockton No. 2 test section and subjected to moving and standing single wheel loads up to 200,000 lb. The cells were installed at several elevations in flexible pavement bases and subgrades of different soil types. A report on these tests is not available at the time this paper is written; however, it is anticipated that a paper covering these tests will be presented at this conference.

CONCLUSIONS

Experience with the test results derived from the use of the WES pressure cell and deflection gages described in this paper has indicated that these instruments furnish measurements of induced stresses and strains which are considered to be reasonably accurate and reliable. It is recognized that certain discontinuities result wherever foreign objects are placed in the soil mass but to date there are no known stress and strain measuring devices which obviate these discontinuities.

It is believed that a primary need exists at the present time for a pressure cell which will accurately measure residual soil pressures over long periods of time. Development of such a cell is included in a comprehensive research program now underway at the Experiment Station.

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TWO TYPES OF SOIL TESTING UNITS

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SUMMARY OF THE FRENCH REPORT

Knowledge of a soil's characteristics enables the problem of foundations to be solved and only the specialised laboratory is qualified to specify them.

The engineer is therefore obliged to rely on the soils laboratory for any job that has to executed on an apparently compressible soil.

There are, however, all kinds of compressible soils just as there are jobs of varying degrees of difficulty.

Now, to set a laboratory in motion for a job of minor importance in a case where the soil is sound in appearance would be needless and expensive.

It is nevertheless necessary to reconcile stability and economy.

Hence the importance to the engineer of a simple and sufficiently accurate means of soil investigation in the field.

The two apparatus described below were designed with this object for a firm of contractors in Algiers at a time when there was not a soils laboratory in Algeria and only two processes for approximate evaluation of soil compressibility were known: these were the multiple or single foot loading plate and the driving of test piles which required a pile driver, and this limited the usefulness of the latter process.

The two units in question are:
a static device made in 1927 and a dynamic device made in 1929.

1. STATIC SOIL TESTING UNIT

This device (Diagram A.) is a load amplifier.

Its three superimposed plates, connected