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DESIGN, CALIBRATION, AND PERFORMANCE OF A DIAPHRAGM PRESSURE TRANSDUCER

by

German P. Lizarazu

B.S., Universidad Boliviana
"TOMAS FRIAS"
Potosi-Bolivia

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Approved by:

Edwin C. Smith
Major Professor

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INTRODUCTION

The determination of stresses in a soil subjected to certain loads and loading characteristics has been the concern of many soils engineers. This report deals with the analysis, the design, and the performance of a pressure transducer. The magnitudes of the forces developed in soil specimens, as detected by the transducer, are correlated with those known to exist as a result of the external loads. The result of this investigation is a better understanding of the internal forces existing in soils under various mechanical loadings.

When the report is divided into two parts, a better explanation of its contents is accomplished. Part I presents a brief account of the theory, design, and operation of a diaphragm type pressure transducer. Such a transducer (Model KSU1) was produced and calibrated. Part II deals with the performance of this transducer. Results are recorded of tests which demonstrate the relations between internal characteristics and external loading.

All laboratory tests were conducted on the triaxial compression machine located in the Soil Mechanics Laboratory of the Department of Civil Engineering. The testing procedure was that recommended in the soil laboratory textbook currently in use at Kansas State University.

Since the performance of the transducer may have been dependent on the nature of the soil in which it was located, two different soils were used as vehicles for the investigation. One soil was a pure sand, and the other was a silty-clay.

Gradation characteristics and other physical properties of these soils can be found in Appendix A of this report.

A summary of the results of the tests performed on the triaxial machine is contained in Part II of this report. Evaluations, based on the figures and tables included herein, are presented in the conclusions. Finally, recommendations for future study and investigation of this subject are made.

SCOPE AND PURPOSE OF THE STUDY

The study covers a review of the literature available on the subject of pressure transducers. This includes the design and calibration of transducers and a description of the more recent methods for the testing of them. The ability of the diaphragm pressure transducer to measure soil pressures with reasonable accuracy when placed in relatively homogeneous soil masses has been demonstrated. Diagrams and tabular data have been included with the aim of correlating testing procedures and results.

PART I

LITERATURE REVIEW

Initial Developments

One of the earliest methods of determining stresses in a defined soil was through the use of soil-pressure cells. A pressure cell developed by Goldbeck (1916) has a relatively thick face plate connected to another plate or piston through a thin and flexible plate (See Fig. 1). The flexible plate acts as a hinge and allows small axial movements of the sensitive part of the face plate. This device is well described by Hvorslev in the "Technical Report S-76-7" (1) of the U. S. Army Engineer Waterways Experiment Station (WES).

Another pressure cell, such as the "pressure pad" developed in Germany, consists of two large circular plates which are welded together along their peripheries (See Fig. 2). The interior space is filled with oil and connected by a tube to the soil surface where a gage for measuring liquid pressures is located. This pressure cell is also described in detail in "Technical Report S-76-7" (1).

A type of pressure cell currently being used correlates pressures with the strains in a diaphragm. As portrayed in Fig. 3, the strains are measured by electrical resistivity foils, and this has the advantage of excellent application in fine-grained and uniform soils. In large or medium-grained soils, however, eccentric load concentrations can appear. The result might be a damage to the diaphragm and future readings of that load would be in error.

Goldbeck Soil Pressure Cell

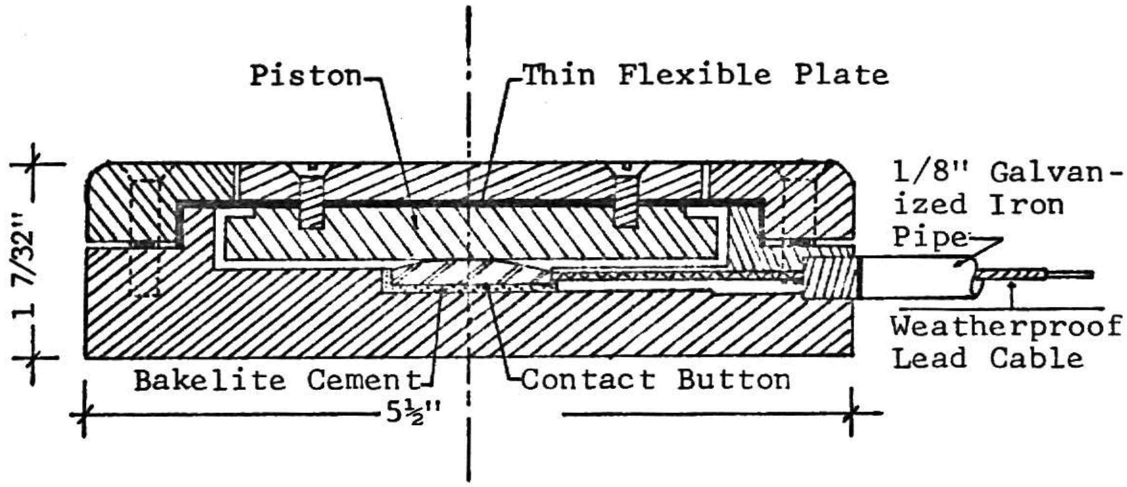


Fig. 1

German Pressure Pad

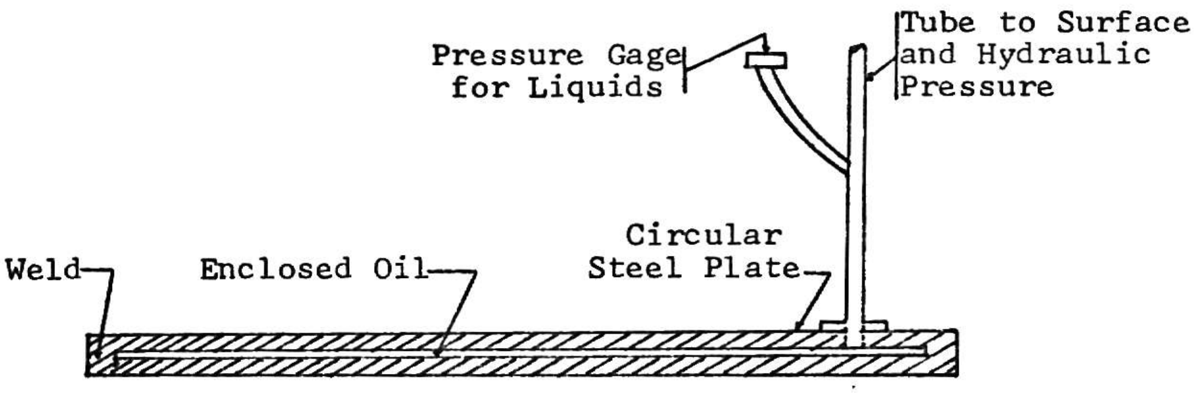


Fig. 2

Disadvantages inherent in the pressure cell have been reduced in the "stress meter" (See Fig. 4) developed by Carlson (2) as well as in the "WES" soil-pressure cells (1). Both cells are similar in that in each there is a thick face plate having a flexible rim. The load is transferred by the face plate through a thin layer of confined liquid which acts on an interior measuring diaphragm. In other details, however, these two cells are quite dissimilar.

Another type of "WES" soil-pressure cell was developed by Osterberg (3) and it employs a double diaphragm chamber. The chamber was filled with standard Ottawa sand which was covered with a rubber membrane for the transmission of the air pressure over the sand. These tests are detailed in the "WES Technical Manual No. 210-1" (3).

The pressure cells described up to this point illustrate the initial work necessary to the development of current pressure transducers. Many of the new transducers use a covered diaphragm which is actuated by a uniform pressure distribution due to the soil loading. They are described in detail in the following section.

Recent Types of Soil-Pressure Transducers

Hvorslev (1) wrote the following in 1976: "A great variety of soil-pressure cells has been developed over the years. In many cases the difference between such cells is in the minor mechanical details or in methods for measuring strains or deflection of diaphragms, such as bonded electrical

Pressure Cell with Diaphragm

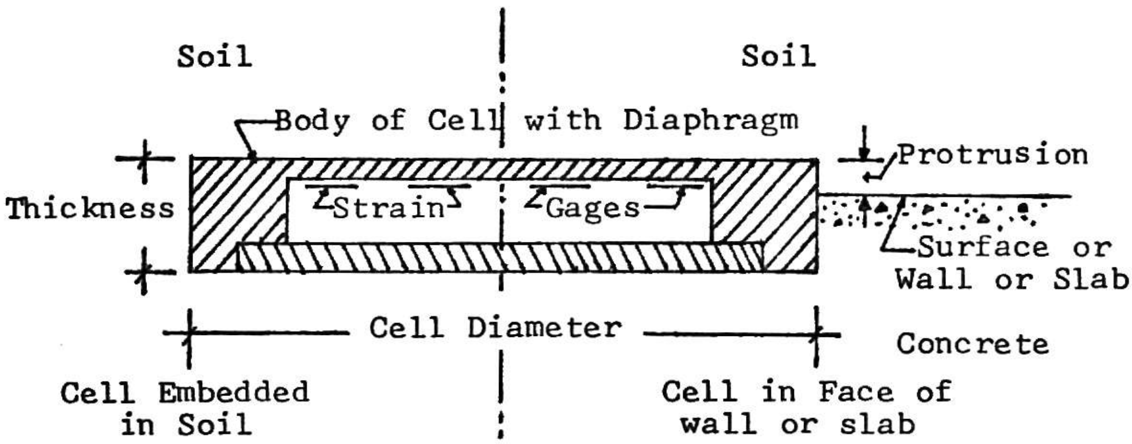


Fig. 3

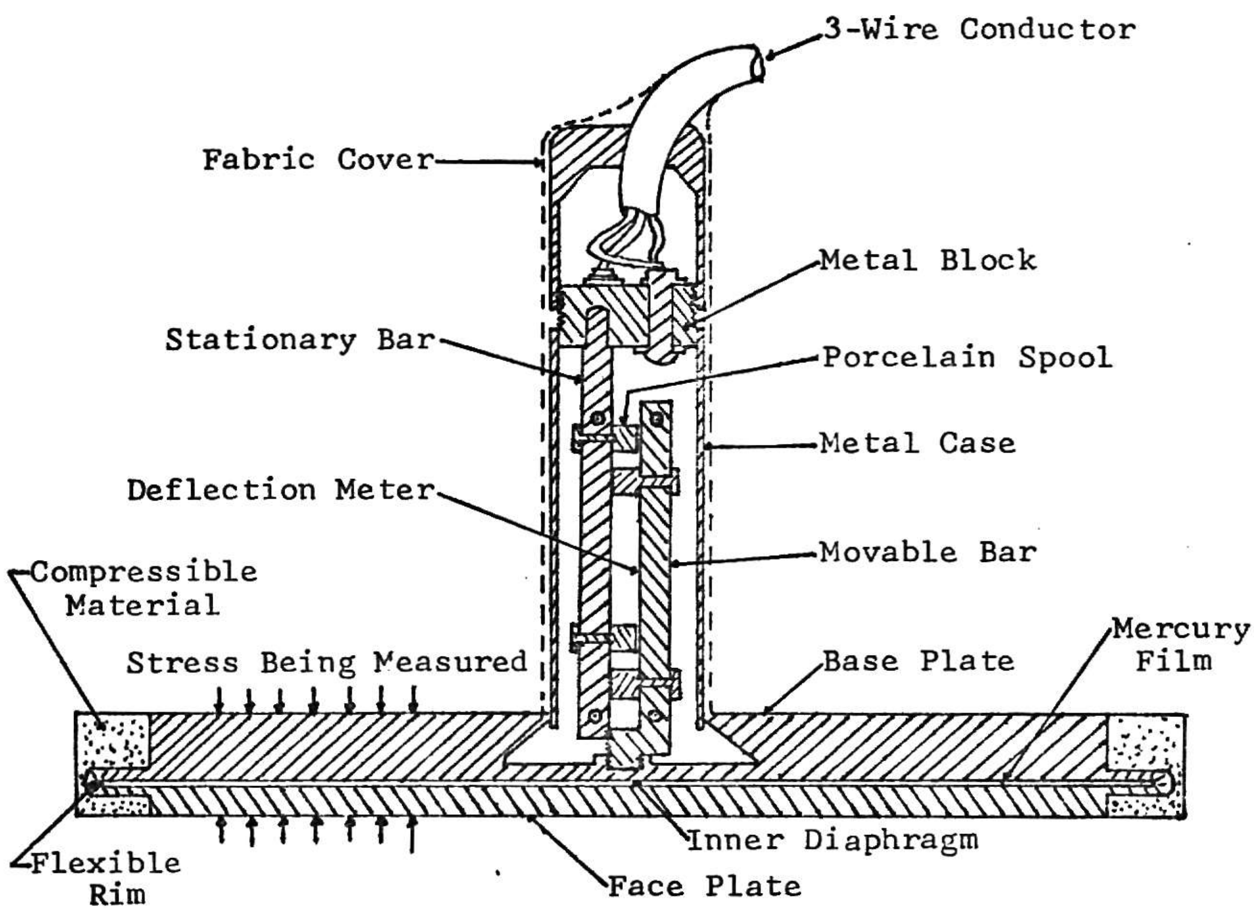


Fig. 4 - Carlson Stress Meter

resistance foils, non-bonded resistance wires, or a vibrating wire." Some pressure cells of the types recently proposed are described briefly in the following paragraphs.

The "WES" double diaphragm soil-pressure cell, shown in Fig. 5, is described in detail by Ingram (4) in which he says, "The active diameter of this cell is 0.75 in., and it has a diaphragm on each side so that the cell is nearly symmetrical with respect to the mid-height plane. This light-weight collar combined with the interior void causes the unit weight of the cell to be close to that of soil, and the cell is suitable for both static and dynamic experiments, provided the soil does not contain stones and the loads on the diaphragms are fairly uniformly distributed."

Another pressure device, developed by Bates (5) and shown in Fig. 6, has the characteristic that the active part of the cell forms an exposed and relatively heavy diaphragm. It has a relatively high sensitivity, however, because of the use of solid strain gages. This device was available for mining investigations and had a rating of 0 - 1,000 psi.

A new type of transducer having omnidirectional sensing has been used to measure soil pressures under both axial and triaxial loadings. It was developed by Verma, Bailey, Schafer, and Futral (6), who presented in a paper to the American Society of Agricultural Engineers, with its employment in a soil compaction study. They make the following statement: "The most common type of soil-pressure transducer is the diaphragm type in which the deflection of a diaphragm due to

Double Diaphragm Pressure Cell

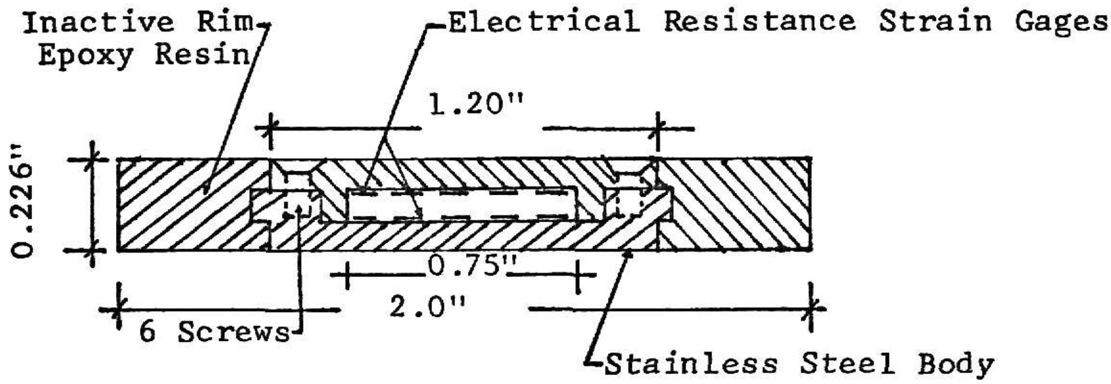


Fig. 5

Soil Stress Cell

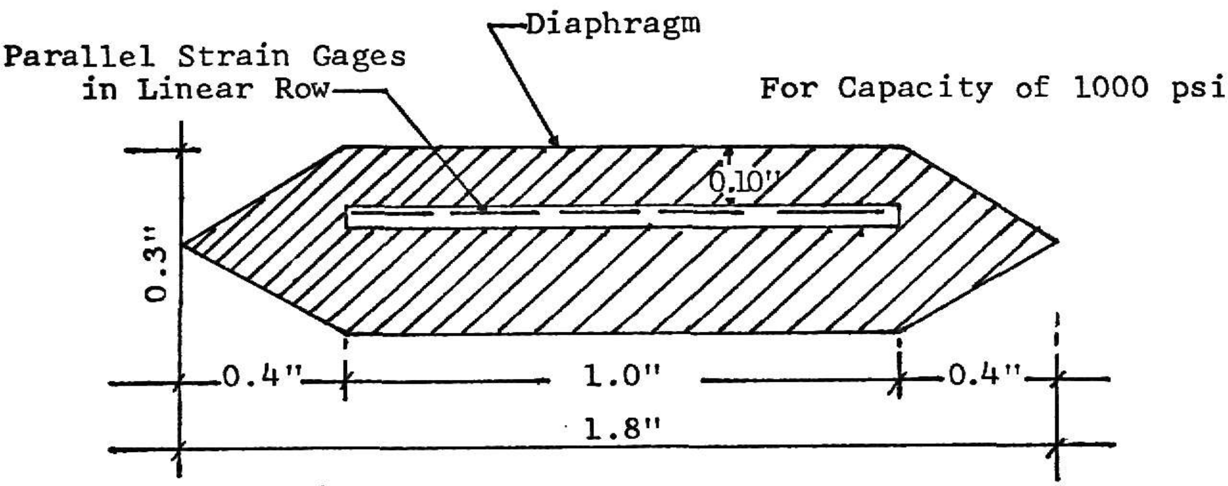


Fig. 6

soil pressure is measured by strain gages or by another deflection measuring method. These transducers usually have one pressure sensing face and are oriented to obtain stress measurement in the direction of interest."

The names of several other investigators should be mentioned. Among these are Cooper, et al. (1957), Kumaran (11) and Dhiman (1970), and Freitag (1971) (12). These men studied pressure transducers and conducted investigations for the determination of soil stresses resulting from external load applications.

The "EA" Strain Gage

The essential element in the performance of the transducer employed in these investigations was the strain gage; a diagram type is shown in Fig. 7. It was developed by Micro-Measurements, a company in Romulus, Michigan, and its characteristics are explained in the "Strain Gage Handbook", of BLH Electronics, Inc., as follows:

"The bonded filament strain gage is an electronic device manufactured from small pieces of wire or foil, paper, and solder. The gage was invented during the latter 1930's by Dr. A. C. Ruge, working at the Massachusetts Institute of Technology on earthquake effect upon large structures, and Mr. E. E. Simons, at the California Institute of Technology working on a similar impact problem. These two men simultaneously developed the bonded filament strain gage in order to measure the magnitude of stress."

A clarifying comment is as follows:

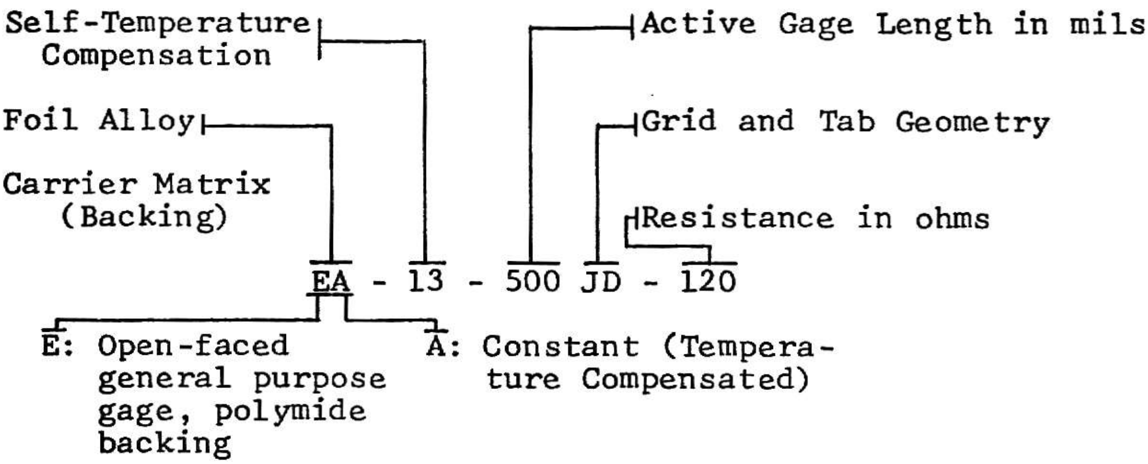
"The term strain gage is best explained by an understanding of the principle of operation. When a load is imposed upon any material object, this item expands or contracts, causing strain in the material. If a grid of wire is bonded to that object, it will stretch or be strained exactly as the surface of the test specimen. A reading of the strain can be calibrated electronically when an electric current is allowed to pass through the filament grid to a particular indicator. The change in resistance of the stretched, or compressed, gage wire is proportional to the strain in the test member. In this manner an engineer is able to tell when the material he is testing is near failure in any given conditions."

Strain gages have been used to investigate strains in many materials under a wide range of environmental conditions. The gage used in these investigations has the following characteristics:

Gage Type*	EA - 13 - 500 JD - 120
Resistance in ohms	120.0 $\pm$ 0.15%
Gage Factor at 75°F ...	2.00 nominal (ASTM E 251-67, Constant Stress Cantilever Method)*
Temperature Range	Cryogenic to approximately +400°F for static measurements; to +500°F for dynamic strain.
Strain Limits	30,000 to 50,000 microstrain (3% to 5%) tension or compression
Fatigue Life	Over 10^7 cycles at $\pm$ 1400 microstrain; over 10^6 cycles at -1500 microstrain; tension or compression
Self-Temperature Compensation	See curve on M-M Catalog, form C1012-B

Cements .... Particularly compatible with certified M-Bond 200 for fast installation

The coding system for this gage is shown below:



<u>Design Considerations for Diaphragm Pressure Transducers</u>

The Micro-Measurements Company, in their technical literature, have written:

"The actual design and development process involves arriving at the best compromise (relative to the performance specifications) of sensitivity, linearity, and frequency response, as determined primarily by the diaphragm diameter and thickness.

The diaphragm pressure transducer considers the following assumptions:

-- uniform diaphragm thickness

-- small deflections

-- infinitely rigid clamping around the diaphragm periphery

-- perfectly elastic behavior

-- negligible stiffening and mass effects due to the presence of the strain gage on the diaphragm

and has the following characteristics:

Sensitivity

The strain distribution in a rigidly clamped thin circular diaphragm under uniform pressure distribution is shown in Fig. 8.

The radial and tangential strains at the center of the diaphragm are identical. The radial strain decreases rapidly as the radius increases, becoming negative, and equal to twice the center strain at the edge. The tangential strain decreases from the center value to zero around the periphery of the diaphragm.

Linearity

The corresponding equations for diaphragm strain and output indicate that the output is proportional to the applied pressure. This precise linearity applies, however, only for vanishingly small deflections. In the case of finite deflections, the diaphragm pressure transducer is inherently non-linear, and, becomes more so, the larger the deflection. As a general rule, the deflection of the diaphragm at the center must be no greater than the diaphragm thickness; and, for linearity in the order of 0.3%, should be limited to one quarter the diaphragm thickness.

Frequency Response

In order to faithfully respond to dynamic pressure, it is necessary that the resonant frequency of the diaphragm be considerably higher than the highest applied frequency. Depending strongly upon the degree of damping in the

Strain Gage Diaphragm-Type
EA - 13 - 500 JD - 120

Fig. 7

Strain Distribution in
Clamped Diaphragm

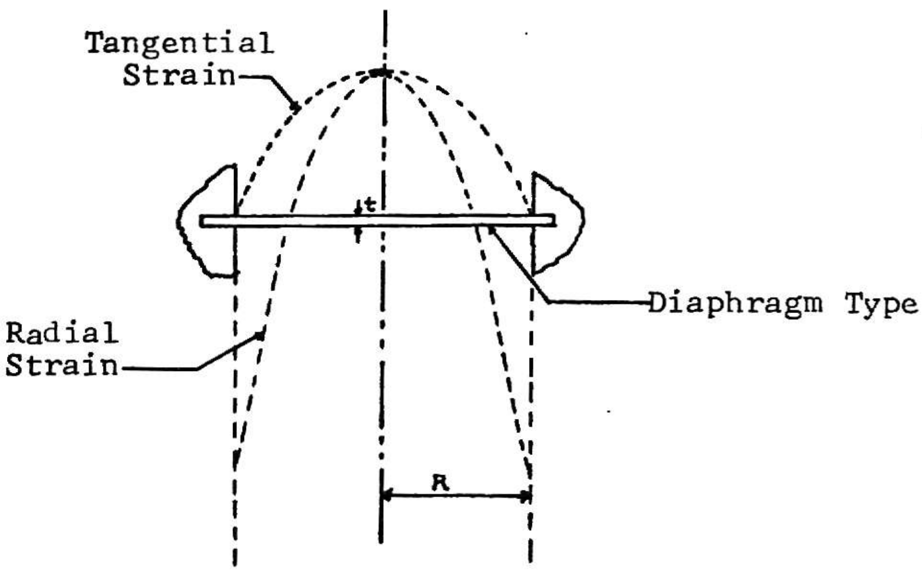


Fig. 8

diaphragm-strain gage assembly and in the fluid in contact with the diaphragm, the resonant frequency should be at least 3 to 5 times as high as the highest applied frequency. The subject of proper design for accurate dynamic response is too complex and extensive to be included here. However, for a transducer subject to high frequencies or to sharp pressure wave fronts involving high-frequency components, careful consideration must be given to frequency response.

Construction

For maximum accuracy and minimum hysteresis, it is common practice to design pressure transducers so that the diaphragm is an integral part of the transducer body. It is neither necessary nor desirable to try to machine the body of the transducer to a sharp internal corner at the junction with the diaphragm. The presence of the fillet radius, however, is merely one of the ways in which practical transducer construction differs from the idealized concept corresponding to the earlier assumptions. Because of this and the other differences, the transducer behavior will necessarily differ from the ideal; and experimental development will obviously be required to optimize the performance of a particular transducer."

PRINCIPLE AND DESCRIPTION OF THE TRANSDUCER

The Model KSU1 soil-pressure transducer (See Fig. 9) has a thin circular steel plate or diaphragm attached to a short metal tube. On the inner surface of the diaphragm is the sensing element which is a strain gage. The principle of operation is that when an external pressure is applied to the outer surface of the diaphragm, the deflection of the diaphragm is sensed by the strain gage. The applied pressure can then be measured by the strain indicator which is in an electrical circuit connected with the strain gage.

The diaphragm is soldered around its periphery to a short tube, and the electrical leads from the strain gage leave the transducer through a small hole in the side of the tube. The end of the tube opposite the diaphragm is covered with another circular plate, and this arrangement permits the free deflection of the diaphragm.

The sensing element is a 0.455-inch (1.25 cm) diaphragm-type strain gage. Its geometry is shown in Fig. 7. Such an arrangement permits the detection of diaphragm deflection in a sensitive manner.

The outer appearance of the transducer is shown in Fig. 10.

It is obvious that the measurement of pressure in a deformed soil is not an easy task. In describing the omni-directional pressure transducer developed by Verma and Futral (7), they state, "Advantages of such an arrangement are that omnidirectional sensing is achieved, the transducer

Soil Pressure Transducer
Model KSU-1

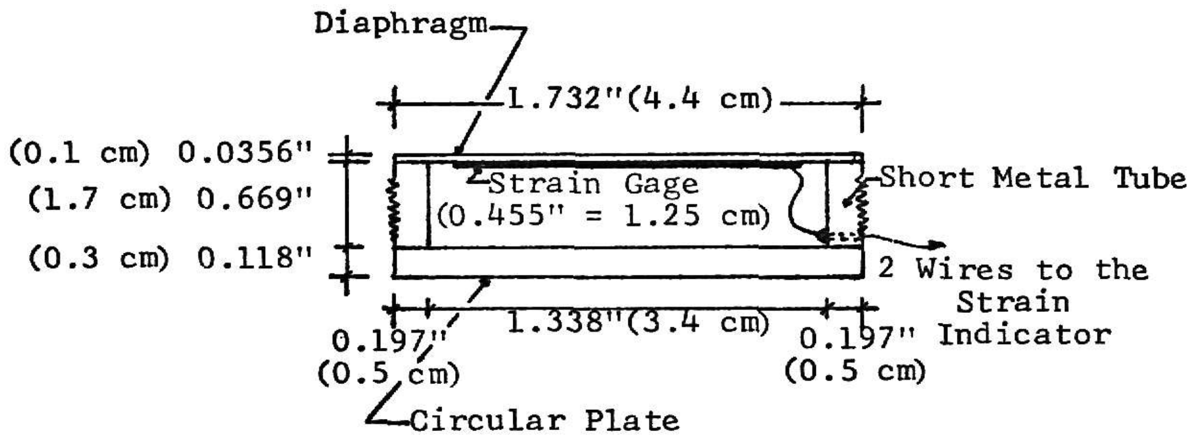


Fig. 9

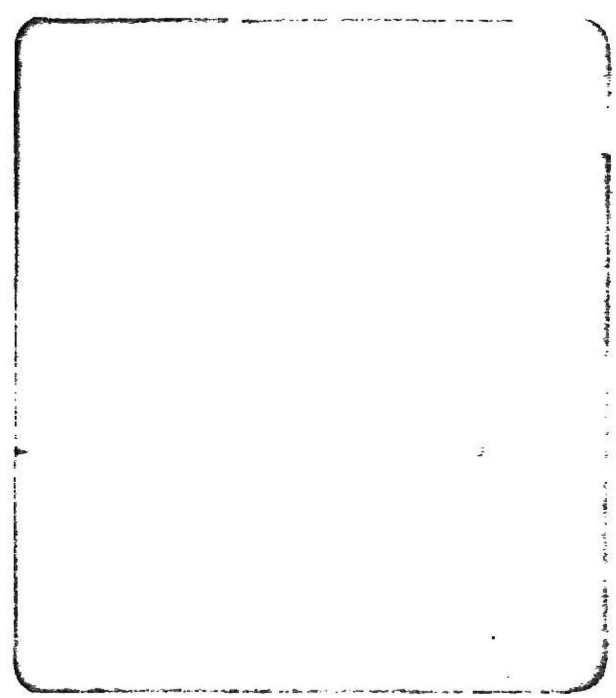


Fig. 10 - Outer Appearance of
the Transducer

is free to deform under load," and "a lesser error due to uneven contact with the media, and the sensing element (strain gage) always is under uniform loading, a condition in which it is calibrated." Since the KSU1 transducer operates under these same principles, the above description is also appropriate to it.

INSTALLATION OF THE STRAIN GAGE

An EA - 13 - 500 JD - 120 strain gage was cemented to the inner face of the diaphragm using an M-Bond 200 adhesive (manufactured by the Micro-Measurements Company). Care was used to insure that the gage was located at the center of the face. To the terminals of the gage, lead wires were soldered, and these were run through a small hole in the side of the tube to the strain indicator.

Proper installation of the strain gage is just as important as proper instrumentation and interpretation of results. For this reason this method of installation was considered a standard procedure. The accuracy of the gage is insured only if quality materials are used and the standard installation procedure carefully followed.

CALIBRATION OF THE SOIL-PRESSURE TRANSDUCER

The commonly used methods for calibrating soil-pressure transducers are direct loading and hydrostatic pressure. In this case the direct loading by means of air pressure was used in the calibration process. The transducer was placed in a small pre-designed chamber, a drawing of which is shown in Fig. 11. The chamber pressure was noted by a pressure gage which had also been calibrated by the standard method. Calibration data for the pressure gage are tabulated in Appendix A.

The chamber was connected to an air pressure hose as shown on its left side in the figure. The chamber pressure made possible the loading of the diaphragm of the transducer which, in the figure, is located on the right side of the chamber. The load on the transducer was read on the strain indicator (Model HWI-D-0110, manufactured by "Strain Sert Company", Bryn-Mawr, Pennsylvania) which was connected in an electrical circuit with the strain gage. Simultaneous readings of chamber pressure, or transducer load, and strain indication could be taken.

A half-bridge tension circuit was used in the strain indicator, and settings of 2.0 and 120 ohms were used for the gage factor and element resistance, respectively. Calibration commenced after all valves, circuits, and instrument settings were checked.

Pressure increments of 10 psi. were used in calibrating the transducer. Calibration was started at zero pressure (gage)

Calibration Chamber for the
Soil-Pressure Transducer

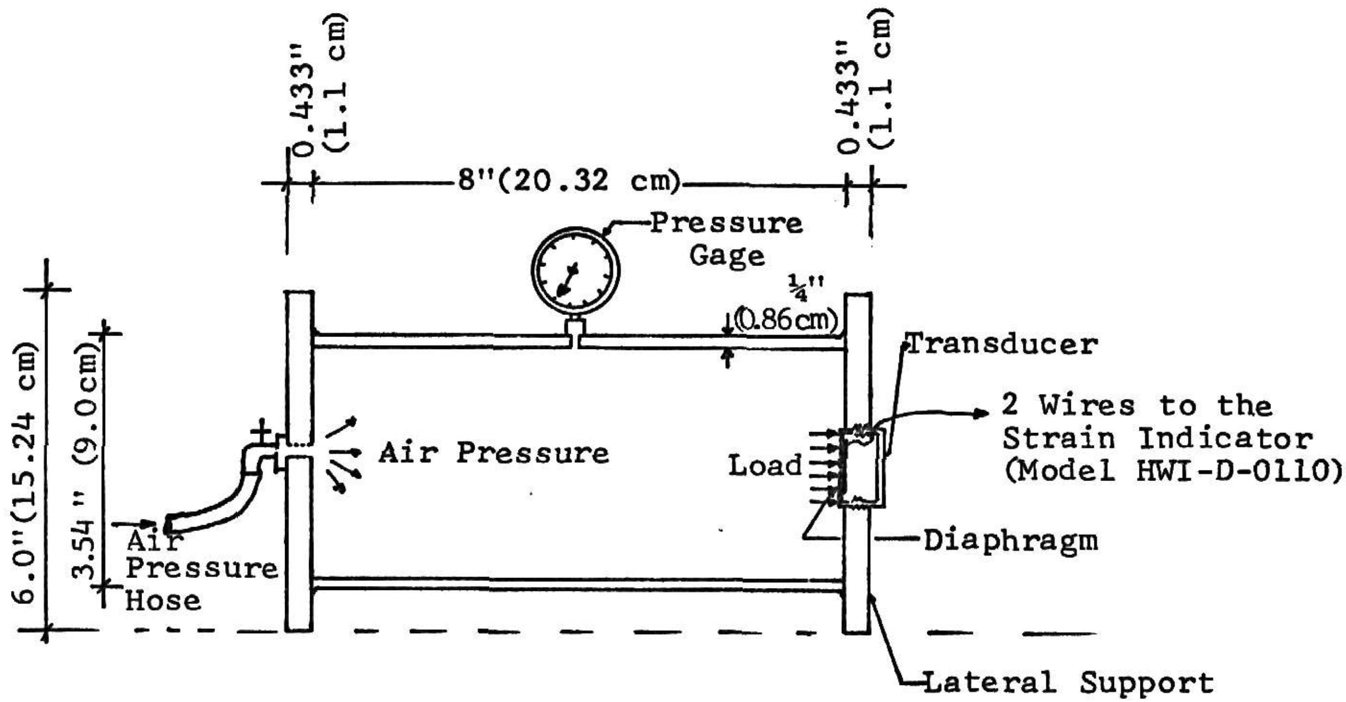


Fig. 11

and continued to 100 psi. Seven trials were conducted, and their average is shown in Table 1. The calibration curve is linear, and because of this a greater reliance is placed in the device. The device is sensitive as will be shown in the results of subsequent investigations.

Table 1 - Transducer Calibration Data

Load (psi.)	Average $\varepsilon = 10^{-6}$ in/in.
0	0
8.30	52.14
18.30	113.57
28.30	174.43
38.30	238.86
48.30	299.00
58.30	362.14
68.30	426.28
78.30	490.57
88.30	550.57
98.30	602.33

PART II

TESTING THE TRANSDUCER ON SAND IN THE TRIAXIAL MACHINE

The experiment which was devised for testing the transducer was selected from a series of standard procedures given in the textbook by Lambe (8). The experiment was performed on a cylinder of soil in which the geometric axis was vertical. The lateral pressure (σ_3) was kept constant while a vertical or principal pressure (σ_1) was continuously applied.

The first test was performed on a dry-loose sand. In order to maintain the cylindrical geometry during its preparation the cylinder was enclosed in a membrane, and a vacuum was employed. The cylinder had a 2.94-inch (7.46 cm) diameter and a 5.35-inch (13.60 cm) length; its diameter-length ratio thereby being 1:1.82. The void ratio was 0.76 and other characteristics of the specimen may be found in Appendix A.

In the testing conditions the transducer was embedded in the center of the sand specimen. Its geometric axis was vertical in order that the vertical or principal stress might be measured. A flat porous stone, 1/4-inch thick, was placed on top of the specimen, and another was placed at the bottom, in an effort to insure uniformity of loading. Some modification of the triaxial test apparatus was necessary in order to connect the lead wires of the transducer to the measuring instrument. The instrument was a strain indicator, Model HWI-D-0110.

Before starting the test the various connections and circuitry were inspected. A lateral pressure (σ_3) of 30 psi.

was applied to the vertical surface of the specimen, and it was then continuously loaded from zero to a pre-determined maximum value of the vertical stress (σ_1). The load was applied at a constant rate of 0.0036 in./min. This loading test can be classified as an "unconsolidated-undrained, stress-strain investigation."

A detailed description of the test is given by Lambe and Whitman (9). They state, "The behavior of dry cohesionless soil is virtually identical with the drained behavior of cohesionless saturated soil," and "in dry sands under normal loading conditions the pore pressure is zero and thus all total stresses are also effective stresses." These statements further clarify the nature of the loading in this test.

During the test continuous recordings of applied load, specimen length, specimen volume, and strain indicator reading were made. Data and results are presented in Table 2 of the Presentation of Data section.

Testing Equipment

The triaxial test apparatus used in these investigations is a product of the Soil Test, Inc. company of Evanston, Illinois (See Fig. 12). The device can be found in the Soils Laboratory of the Department of Civil Engineering. It is supplied with the necessary platens, loading piston, pressure chamber (Model T-108-B), pressure gage, fluid damping gear, variable speed pump, fluid and fluid reservoir, and fluid circuit.

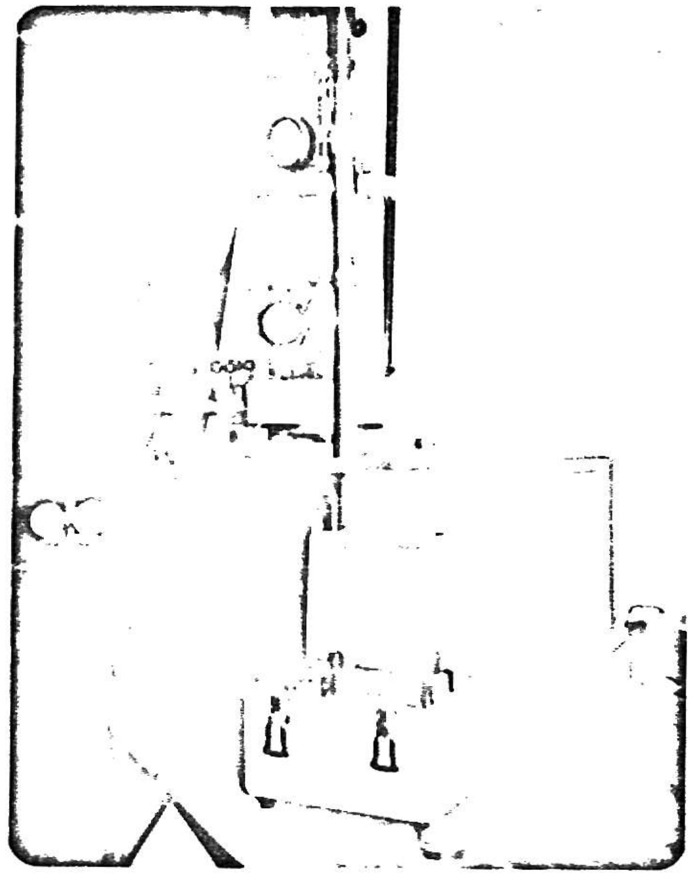


Fig. 12 - Triaxial Testing Device

TESTING THE TRANSDUCER ON SILTY-CLAY IN THE TRIAXIAL MACHINE

The experiment devised for testing the transducer on silty-clay was similar to that employed in the case of sand. The exception was that the silty-clay specimen was pre-consolidated to the Standard Proctor Compaction. This loading test can therefore be classified as a "consolidated-undrained, stress-strain investigation."

Details of the compaction process are given in Taylor (10). After compaction the specimen was trimmed to a desired size of 2.79-inch (7.09 cm) diameter and a 4.61-inch (11.71 cm) length. Care was used in embedding the transducer in the specimen in the same configuration as was the case of the sand specimen.

In the triaxial machine the axial load (σ_1) was applied at the rate of 0.0036 in./min. and its magnitude was then observed by means of the pressure-load cell (See the calibration curve in Appendix A). As in the case of the sand specimen a lateral pressure (σ_3) of 30 psi. was applied, and this was sufficient to maintain lateral support of the specimen. Continuous recordings of the same data taken in the case of the sand specimen were also made in this case. Data and results are presented in Table 2 of the Presentation of Data section.

PRESENTATION OF DATA

Laboratory Tests

The two types of soil on which the triaxial loading tests were conducted were:

1. A river sand taken from the Kansas River at Manhattan, Kansas, and

2. A silty-clay taken from the Kansas River Valley at Manhattan, Kansas.

The physical characteristics of these soils are given as follows:

	Sand	Silty-clay
Specific Gravity	2.64	2.72
Natural Moisture Content	0.14%	18%
Atterberg Limits	Non-Plastic	Plastic
Classification: AASHO	A-1-6 (0)	A-6 (0)
Unified	SP	CL

The laboratory data sheets for these tests may be found in Appendix A.

The results of the triaxial loading tests are in Table 2 on the following page.

Table 2

Sand		Silty-clay	
Applied Stress Load/Area psi.	Transducer Pressure psi.	Applied Stress Load/Area psi.	Transducer Pressure psi.
0	0	0	0
1.48	1.0	2.28	1.1
6.93	6.0	6.10	4.0
16.20	13.0	9.38	7.0
21.30	17.5	12.20	10.0
31.14	27.5	15.08	12.9
37.41	34.0	18.30	16.0
40.17	37.5	23.65	21.1
45.38	45.0	25.54	24.2
48.84	49.0	27.32	26.0
51.41	53.0	30.27	29.0
52.81	57.0	33.31	33.5
55.38	61.0	33.51	37.0
		37.60	40.5

ANALYSIS OF DATA

The bases for this analysis are the plots of the transducer pressure versus the applied stress which are shown in Figs. 13 and 14.

Triaxial Loading on Dry Sand

Data recorded in Table 2, as regards the test on the sand specimen, form the plot in Fig. 13. The relation between the transducer pressure and the applied stress can be adequately described as linear. This is especially true at lower applications of stress (0-10 psi.) where the pressures as measured by the transducer were practically equal to the applied stresses. Less correlation is obtained in the range of 10-50 psi., and for the larger applications of stress (greater than 50 psi.) the pressures as measured by the transducer were correspondingly lower. This may be explained as being the result of two effects. First, at an applied axial stress of 50 psi. the specimen showed visual evidence of failure. Second, when the applied axial stress becomes appreciably larger than the lateral stress, the stress on the face of the diaphragm may no longer be a uniform distribution.

Triaxial Loading on Silty-clay

Data recorded in Table 2, as regards the test on silty-clay, form the plot in Fig. 14. The results of the test on the silty-clay specimen were quite similar to those on the

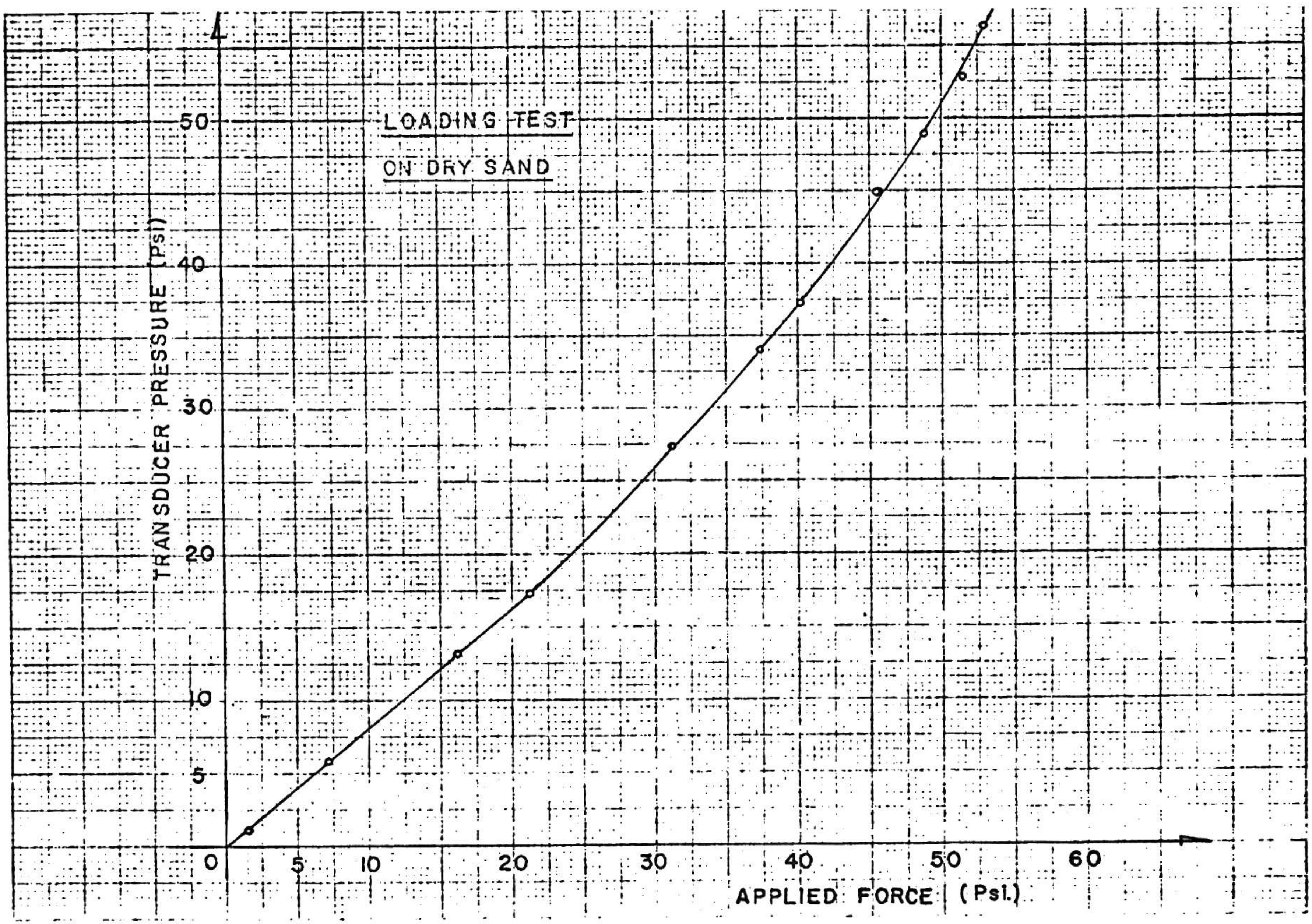


Fig. 13 - Triaxial Loading on Dry Sand

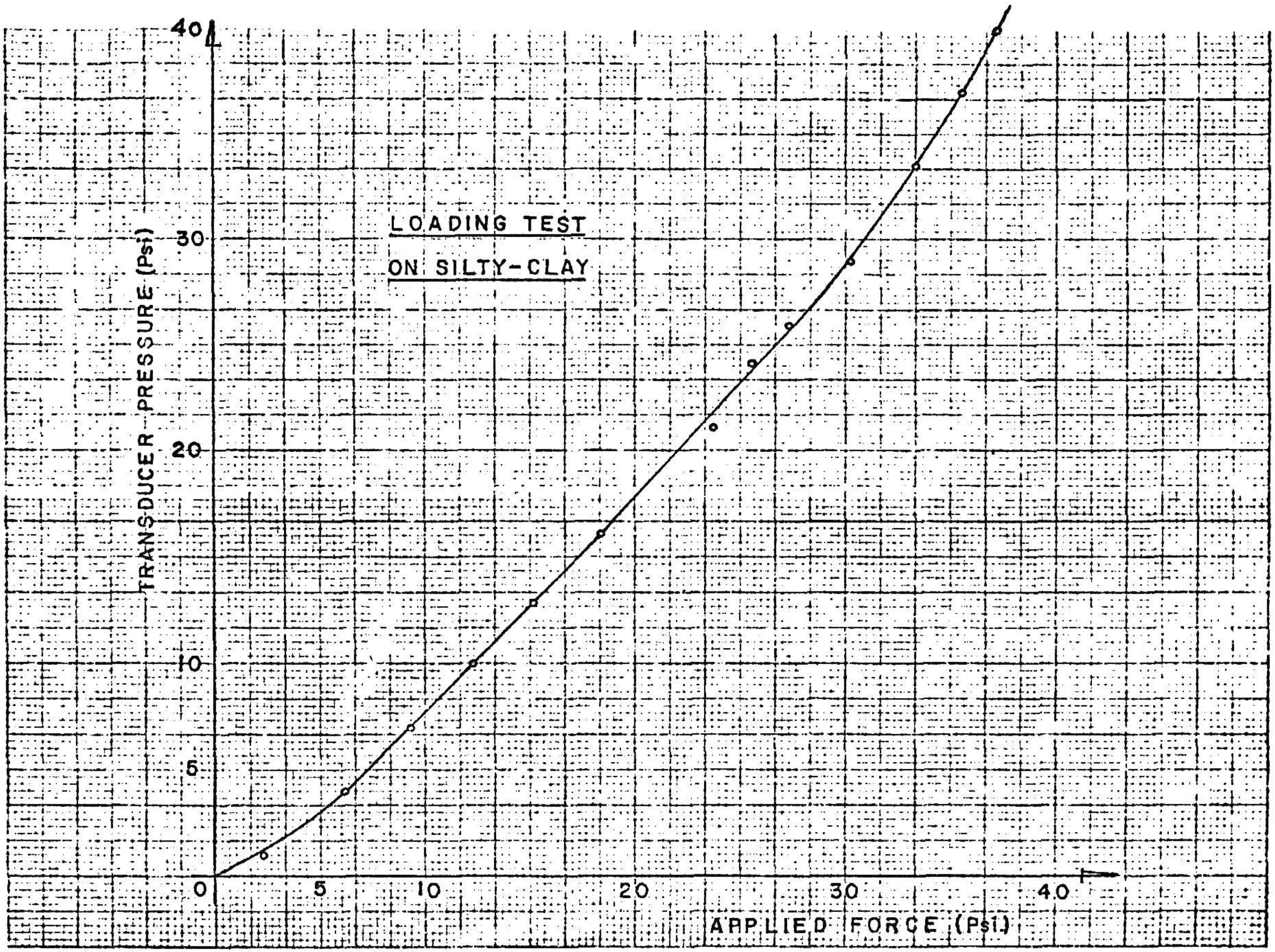


Fig. 14 - Triaxial Loading on Silty-clay

sand specimen. However, because failure of the silty-clay specimen was visually observed at a lower applied axial stress, transducer readings commenced deviating at an applied axial stress lower than that corresponding stress in the sand experiment. Thus, results are plotted in Fig. 14 in a range of applied axial stress from zero to 40 psi.

Although the silty-clay specimen had a moisture content of 18% and was precompacted to a Standard Proctor Compaction, this specimen was weaker than the sand specimen. An explanation is that in embedding the transducer in the silty-clay specimen, the soil in the vicinity of the incision was partially weakened. Failure of the silty-clay during the test was visually observed on the line of the transcision. Nevertheless, a close linear relation existed between the transducer stress and the applied axial stress up to values of 40 psi. of applied axial stress.

CONCLUSIONS

(a) For the measurement of axial stress in the static loading of both loose and precompacted soil samples in a triaxial machine the transducer response was linear and compared favorably to the applied axial stress up to the point of failure of the specimen.

(b) In the dry sand sample the transducer measured a "total" normal stress which was also the "effective" normal stress, there being no moisture present. In the silty-clay sample the transducer also measured the "total" normal stress which was also the "effective" normal stress since the moisture which was present had no effect on the stressed plane. Drainage of the moisture was non-existent.

(c) The stress distribution on the transducer is affected by the transducer thickness-diameter ratio. Large values of this ratio can result in under-registration of stress.

(d) Since the transducer only measures pressure in one direction, careful orientation is required in its placement.

(e) In precompacted soil samples the soil is weakened by the insertion of the transducer in a specimen for testing in the triaxial machine if insertion takes place after compaction.

RECOMMENDATIONS FOR ADDITIONAL INVESTIGATIONS

Successful results were obtained in using the pressure transducer (diaphragm type) for measuring axial stresses in specimens in a triaxial machine on which the lateral stresses were 30 psi. By increasing the lateral stress to larger values, it is expected that larger axial stresses could thereupon be successfully measured since failure would not occur until larger axial stresses were reached. This remains to be determined and should be investigated.

Successful results in the use of this transducer in certain triaxial tests were attained. It is recommended that the transducer be tested in other types of loading. For instance, it could be placed in a soil bin at various burial levels, and stresses resulting from various surface loadings could be measured by the transducer and compared to the theoretical values of the stresses.

The fidelity of the transducer in measuring stresses under other loading conditions should also be observed in various soils and in varying moisture contents.

ACKNOWLEDGMENTS

I express my most sincere appreciation and gratitude to Dr. Edwin C. Lindly for the valuable advice, guidance, and reviewing of the manuscript of this report.

I also extend my gratitude to Dr. Robert R. Snell, Head of the Department of Civil Engineering, to LASPAU, The Latin American Scholarship Program of American Universities, and to La Universidad Boliviana "Tomas Frias" who gave me the opportunity to study at Kansas State University. Professor Wayne W. Williams, Chairperson and Dr. Henry V. Beck, members of the Advisory Committee are hereby gratefully acknowledged.

I want to extend my appreciation to Peggy Selvidge for typing this report.

Finally, I want to extend a special thanks to my family for their comprehension.

Appendix A

Physical Characteristics of the Sand, Silty-clay and the Data of the Triaxial Loading Tests

Table 3 - Sieve Analysis of Kaw River Sand

Sieve Analysis

Soil Sample: Dry Sand K.R.M.K. Date: August 1977 Tested by G.L.P.

Wt. Soil = 246.4 grs.

Sieve No.	Sieve Opening (mm)	Wt. Soil Retained (gr)	Percent Retained	Cumulative Percent Retained	Percent Finer
10	2.00	3.83	1.55	1.55	98.45
20	0.840	34.99	14.20	15.75	84.25
40	0.420	103.73	42.09	57.84	42.16
60	0.250	76.77	31.16	89.00	11.00
140	0.105	24.02	9.75	98.75	1.25
200	0.074	1.35	0.55	99.30	0.70
pan	---	1.56	0.63	99.93	0.07

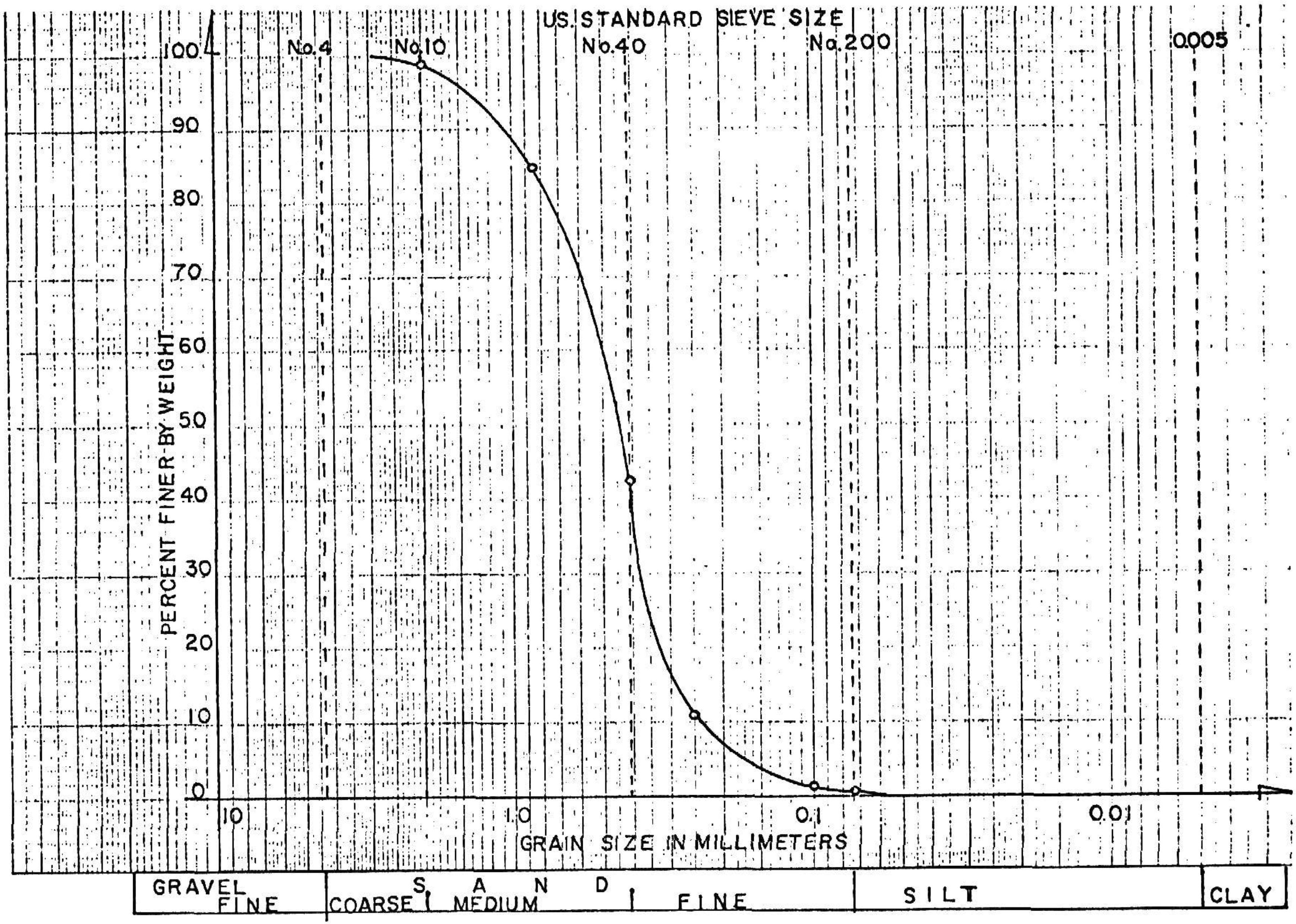


Fig. 15 - Sieve Analysis on Dry Sand

GRAIN SIZE ANALYSIS-HYDROMETER METHOD Data Sheet 7

Project Master's Report Job No. 2

Location of Project Kansas River Valley Boring No. 2 Sample No. 2

Description of Soil Silty-clay Depth of Sample --

Tested By German Lizarazu Date of Testing 8/12/77

Hydrometer analysis

Hydrometer no. 152-H G_s of solids = 2.7 a =

Dispersing agent Deflocculant Amount 1.0 gr Wt. of soil, W_s 50.0

Zero correction -- Meniscus correction 0.5

Date	Time of reading	Elapsed time, min	Temp., °C	Actual Hyd. reading R_a	Corr. Hyd. reading R_c	% Finer	Hyd. Corr. only for meniscus, R	L from Table 6-5	$\frac{L}{t}$	K from Table 6-4	D, mm
8/12/77	4:00	0	24.0								
		1/4		45.0	44.5	89.0					0.0780
		1/2		41.0	40.5	81.0					0.0550
		1		35.3	34.8	69.6					0.0400
		2		28.5	28.0	56.0					0.0300
	4:05	5		20.8	20.3	40.6					0.0210
	4:10	10		16.3	15.8	31.6					0.0150
	4:20	20		14.5	14.0	28.0					0.0110
	4:40	40		13.0	12.5	25.0					0.0076
	5:00	60		12.5	12.0	24.0					0.0064
	5:20	80		12.1	11.6	23.2					0.0055
	5:40	100		11.8	11.3	22.6					0.0050
8/12/77	8:00	240	23.0	11.2	10.7	21.4					0.0033
8/13/77	12:00	1200	22.0	10.0	9.5	19.0					0.0014

$R_c = R_{actual}$ − zero correction + C_T % finer = $R_c(a)/W_s$ $D = K\sqrt{L/t}$

Table 4 - Hydrometer Analysis on Kansas River Valley Silty Clay

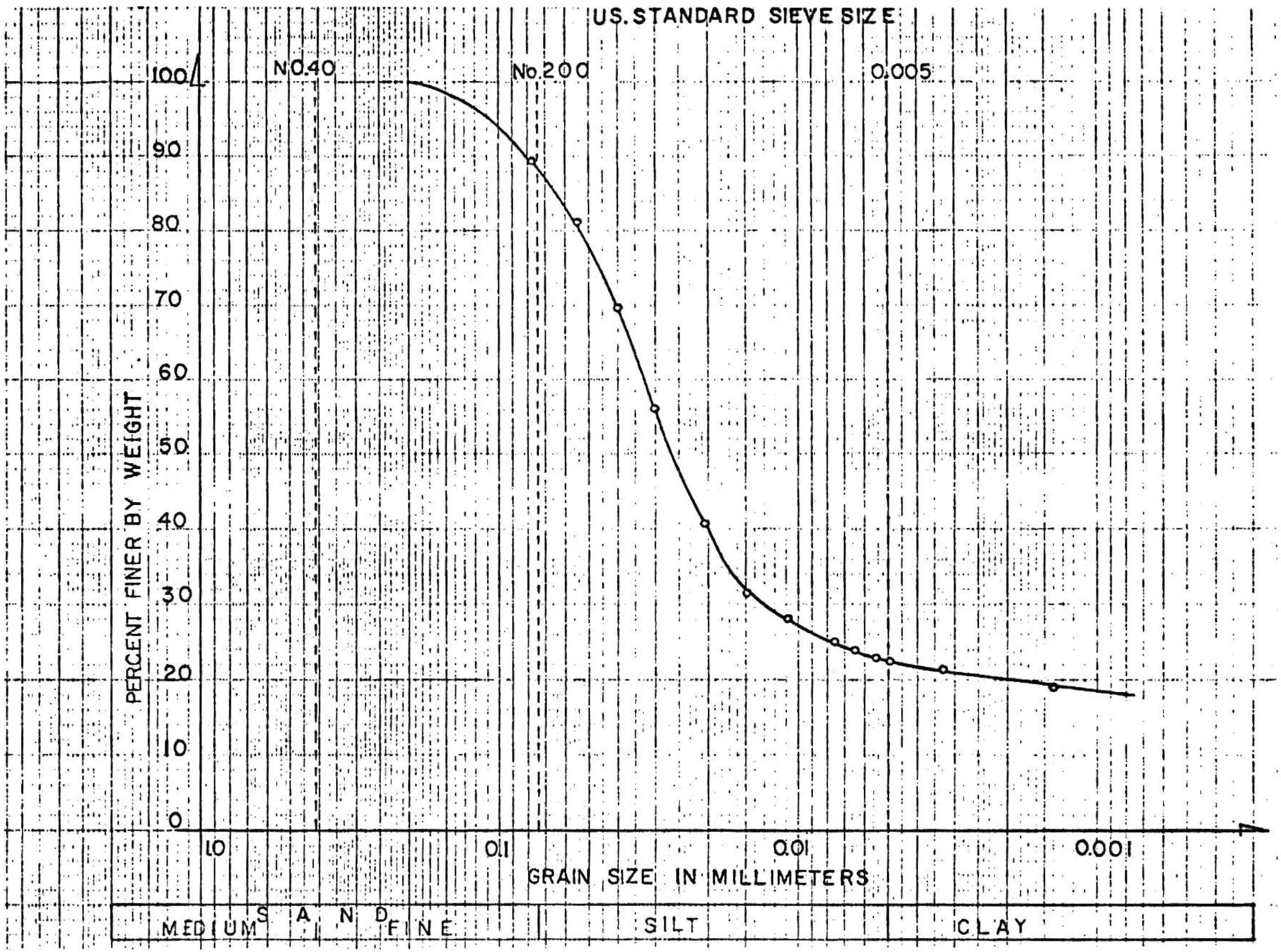


Fig. 16 - Hydrometer Analysis on Silty-clay

Table 5 - Specific Gravity Tests

Soil Sample:	Sand		Silty-clay	
Determination No.	1	2	1	2
Bottle No.	13	12	4	7
Wt. Bottle + Water + Soil (W_1), g.	773.09	774.06	764.43	765.23
Temperature T °C	27.0	26.9	26.4	26
Wt. Bottle + Water (W_2), g.	680.27	679.35	674.39	573.78
Evaporating Dish No., g.	10	11	9	8
Wt. Dish + Dry Soil, g.	64 .79	649.15	619.93	618.48
Wt. Dish, g.	500.65	497.32	477.64	478.40
Wt. Soil (W_s), g.	149.14	151.83	142.29	140.08
Sp. Gravity of Water at T (GT)	0.9965	0.9965	0.9967	0.9968
Sp. Gravity of Soil (G)	2.640	2.643	2.714	2.716

$$G_s = \frac{W_s\ GT}{W_s - W_1 + W_2}$$

Sp. G (sand) = 2.64

Sp. G (silty-clay) = 2.71

Date: July 1977 Tested by: G.L.P.

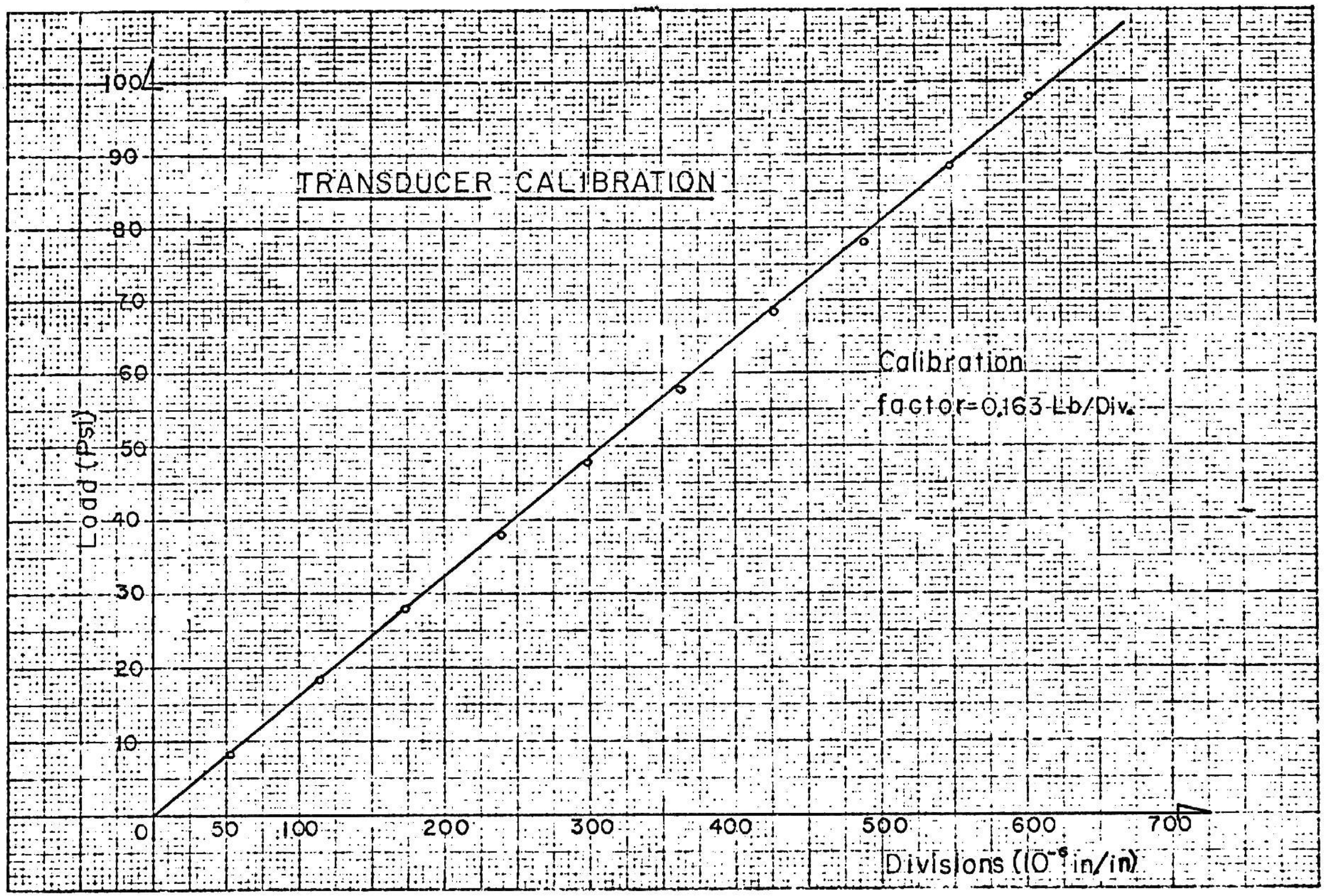


Fig. 17 - Transducer Calibration

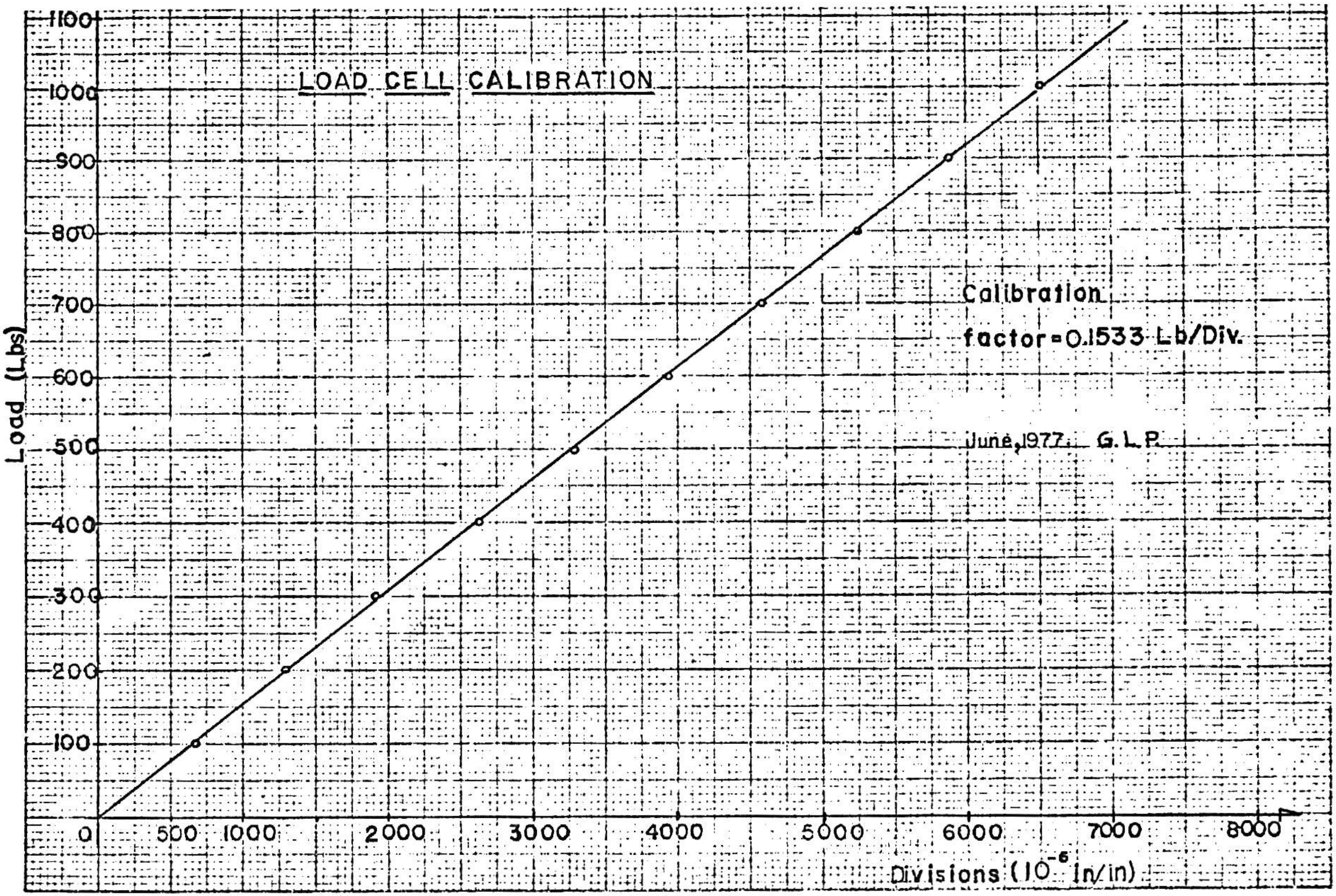


Fig. 18 - Load Cell Calibration

Table 6 - Data of Triaxial Loading Test on Dry Sand

σ_3 (psi)	ε (10^{-3} in)	ΔL (in)	Load Cell (10^{-6} in/in)	Transd. (10^{-6} in/in)	Stress Transd. (psi)	$\varepsilon = \frac{\Delta L}{Lo}$ (%)	Area (in^2)	Axial Load (lbs)	P/A (psi)	Observ.
30.0	0	0	0	0	0	0	6.770	0	0	Lo = 5.35"
	4	0.004	66	4	1.0	0.075	6.775	10	1.48	
	8	0.008	255	20	6.0	0.149	6.780	47	6.93	
	16	0.016	700	71	13.0	0.299	6.790	110	16.20	
	22	0.022	950	116	17.5	0.411	6.798	145	21.30	
	30	0.030	1400	168	27.5	0.561	6.808	212	31.14	
	36	0.036	1650	210	34.0	0.673	6.816	255	37.41	
	40	0.040	1800	230	37.5	0.748	6.821	274	40.17	
	48	0.048	2000	275	45.0	0.897	6.831	310	45.38	
	54	0.054	2155	303	49.0	1.009	6.839	334	48.84	
	60	0.060	2255	325	53.0	1.121	6.847	352	51.41	
	66	0.066	2300	350	57.0	1.234	6.854	362	52.81	
	72	0.072	2450	374	61.0	1.346	6.862	380	55.38	

Table 7 - Data of Triaxial Loading Test on Silty-clay

σ_3 (psi)	ε (10^{-3} in)	ΔL (in)	Load Cell (10^{-6} in/in)	Transd. (10^{-6} in/in)	Stress Transd. (psi)	$\varepsilon = \frac{\Delta L}{Lo}$ (%)	Area (in^2)	σ_1 (lbs)	P/A (psi)	Observ.
30.0	0	0	0	0	0	0	6.140	0	0	Lo = 4.016"
	1	0.001	75	8	1.1	0.024	6.141	14.0	2.28	
	12	0.012	240	25	4.0	0.299	6.158	38.0	6.10	
	30	0.030	375	46	7.0	0.747	6.186	58.0	9.38	
	39	0.039	500	61	10.0	0.971	6.200	76.0	12.20	
	63	0.063	620	82	12.9	1.569	6.234	94.0	15.08	
	87	0.087	750	103	16.0	2.166	6.276	115.0	18.30	
	104	0.104	960	132	21.1	2.589	6.303	149.0	23.65	
	125	0.125	1060	150	24.2	3.112	6.337	162.0	25.54	
	140	0.140	1130	161	26.0	3.486	6.362	174.0	27.32	
	160	0.160	1270	179	29.0	3.984	6.395	194.0	30.27	
	190	0.190	1400	207	33.5	4.731	6.445	215.0	33.31	
	206	0.206	1500	226	37.0	5.129	6.472	230.0	35.51	
	230	0.230	1575	248	40.5	5.727	6.513	245.0	37.60	

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DESIGN, CALIBRATION, AND PERFORMANCE OF A DIAPHRAGM PRESSURE TRANSDUCER

by

German P. Lizarazu

B.S., Universidad Boliviana
"TOMAS FRIAS"
Potosi-Bolivia

1973

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1977

ABSTRACT

A flexible, thin circular (Diaphragm-Type) plate of 1.732" outside diameter with a sensing element (strain gage) was used to measure stresses in soils. This device, called a transducer, was embedded in two kinds of soils: loosely dry sand and silty-clay. The loading patterns were conducted in the triaxial machine with all the modifications previously made.

A linear relation was found between the transducer response and the applied mean normal stress in both the dry sand and the silty-clay. However, in the precompacted soil (silty-clay) the range of results was lower than in sand because the specimen was weaker after the transducer was embedded in the soil.

Nevertheless, all the investigations made with this type of pressure transducer should be considered as successful because the results obtained herein are compared favorable with the expected results.