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DEVELOPMENT OF A SMALL SOIL STRAIN GAGE

Final Report
March 1963

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Research Directorate
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Air Force Systems Command
Kirtland Air Force Base
New Mexico

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HEADQUARTERS
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PREFACE

This is the final report on Armour Research Foundation (ARF) Project No. K257, Design and Development of a Small Soil Strain Gage, sponsored by the Air Force Special Weapons Center, Kirtland Air Force Base, Albuquerque, New Mexico. The work was performed during the period of May 1962 to November 1962.

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Respectfully submitted,

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ABSTRACT

A small strain gage was developed for the measurement of static and dynamic strains when embedded in soil samples. The gage itself consists of two sets of two coil discs; associated instrumentation includes electronic driving, amplifying, and recording circuitry. One set of coils is embedded in soil as the strain sensing element; the other is externally positioned to serve as a reference. The principle of operation is that of an air core differential transformer with a null balancing system to permit accurate measurements of small strains.

The gage is a reliable precision measuring device. Results of static and dynamic evaluations prove that the coils can be consistently placed in soil specimens within the spacing and alignment requirements. Thus, the gage accurately defines the relative position of two points in the soil and accurately measures the change in spacing of these points when the specimen is strained.

All indications are that the gage is well suited for the measurement of strain in soil and that with further investigation of the effect of gage presence and appropriate modifications to reduce this effect, the gage may be used to reliably measure both static and dynamic strains within a very small gage length.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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1. INTRODUCTION

The objective of the program was to design, develop and verify the operation of a small gage to measure strain in soil. The gage was intended for the laboratory study of small soil samples under both static and dynamic loading conditions.

To determine strain, the change in spacing between two points a finite distance apart, must be known. The relative displacement of two points in soil may be measured in two ways. First, the absolute displacement for each point may be determined, the differential displacement being the difference between the two. This method requires either a fixed displacement reference outside the soil mass, or integration of acceleration or velocity measurements.

A fixed displacement reference is impractical for most dynamic applications. Integration and subtraction of the resulting numbers, which are usually large as compared to their difference, introduces error of the magnitude of the measurements.

The second, more practical scheme is direct measurement of differential displacement. This may be accomplished by a transducer connecting two gage points (coupled strain gage). Gages of this type have been developed and are available. Their use as a soil strain gage has usually been on a larger scale for field testing. The principal disadvantage of this type gage is the presence of the transducer which requires physical connection between the gage points. Such a physical connection introduces a body foreign to the soil within the gage length, influencing the natural response of the soil to deformations. Furthermore, it complicates placement in that moving linkages must be protected from binding due to interference of soil particles.

It appeared feasible to develop a gage which would have no physical connection between the gage points (uncoupled strain gage), thus eliminating the linkage and its disturbance and restraint on the surrounding soil. A device based on a transformer principle of operation had previously been used at the Armour Research Foundation to detect defects in rolled steel plates. Preliminary investigations indicated that this principle could be adapted to use as a soil strain gage. This gage would be essentially an air-core differential transformer, the sensing elements being the primary and secondary windings. Considering the advantages offered by an uncoupled, direct measuring gage, we decided to direct the major effort to the development of a gage of this type.

2. PURPOSE AND SCOPE OF INVESTIGATION

Ideally it is desirable to measure strain at a point. Physically this is not possible. Instead, it is necessary to determine an average strain obtained by measuring the change in spacing of two points a finite distance apart. The purpose of this research was to produce a gage to reliably make strain measurements in soil. Reliability of measurement is meant to include: first, that the output of the gage accurately represents the relative initial position of two points in the soil and subsequent differential movements of these points; and second, that the movements measured are those which would have taken place had the gage not been present.

The program consisted of the following phases: (1) feasibility study and prototype gage design, (2) bench evaluation of gage performance, (3) evaluation of embedded gage performance for accuracy of measurements under static and dynamic loads, (4) preliminary study of the significance of gage presence on the measurements made, and (5) final gage design and fabrication.

Phases (1) and (5) were continuous throughout the program. Once it had been established that the gage concept was feasible and a prototype gage was constructed, an optimum design was sought through refinement of the sensing elements and the backup electronic equipment.

Work on phase (2) began immediately after the development of the prototype gage. This work was conducted in sufficient detail to determine adequately the suitability of the gage for use in soil. The third and fourth phases were conducted simultaneously. The fourth phase was by far the most difficult. Proper evaluation would require a comparison of different gage sizes in a controlled test series in which all parameters involved could be evaluated. Neither the range in gage sizes nor the time required for such a study was available for an investigation of this type. Instead, it was decided to conduct a simple test in which gage performance as defined in phase (3) could be thoroughly evaluated and from which some feeling for the effect of gage presence could be obtained. This investigation served quite satisfactorily for its primary purpose, and at the same time established, beyond any doubt, the necessity of a thorough study of the effects of gage presence.

3. GAGE DESIGN AND DEVELOPMENT

3.1 Design Criteria

The design criteria for the soil strain gage were based upon considerations of the measurements to be made, the ideal concept of strain, the operational environment, soil-gage interaction, and problems of gage placement.

The measurements to be made were (1) initial gage length in soil and (2) changes in this length as the soil deformed. The physical significance of the results depends on the accuracy with which these measurements can be made. It is imperative that the gage be sensitive to small differential axial movements, yet be insensitive to the lateral and rotational movements created by lateral and shearing strains.

Strain cannot be determined ideally, i.e., at a point. It is necessary instead, to use an average strain obtained by measuring the change in spacing of two points a finite distance apart. Obviously, only when the strain is uniform in the zone between the gage sensing elements is the measured average strain equal to the true strain. This physical limitation becomes most significant in the determination of strains produced by a passing shock wave. Under these conditions, the strains will change most rapidly in the vicinity of the shock front. Hence, the strain in the region between the gage elements will be very non-uniform as the shock front passes from one gage element to the other. The severity of this limitation in actual application will depend upon the rise time of the wave front, but it is clearly desirable to make the gage length as small as possible.

Frequency response is also important in dynamic measurements. High-frequency response determines the minimum rise time the gage is able to sense. In practice, rise time may vary from almost instantaneous, as would occur at the soil surface under an air shock, to the gradually applied static load. Thus, the greater the range of frequency response, the greater the range of application of the gage.

Considerations of operational environment dictate that a gage designed for use in soil must necessarily be insensitive to soil type and to the moisture which the soil may contain.

Soil-gage interaction creates a difficult problem. Ideally, it would be desirable to design a gage which would match perfectly the characteristics of the soil which it displaces. Practically, this is not possible. The characteristics of soil vary not only with soil type, such as clays, sands, and silts, but variations occur within any one type depending on moisture content and degree of compaction. One can only hope to minimize interaction effects by making the size of the inserted components as small as possible and by designing the gage so that it is actuated with a minimum resistance to free movement of the soil. For dynamic applications it is also desirable to have the density of the gage components in the same range as the density of the soil in order to minimize inertial effects.

Problems associated with gage placement must also be taken into consideration in gage design. Since the gage under consideration is intended for laboratory use, the problem of gage placement is not as acute as in the case of a gage intended for field use. Frequently field measurements are desired in natural soil deposits. Meaningful _in situ_ measurements with an embedded gage require extremely careful gage placement. Excavation for gage insertion must be accomplished with a minimum of disturbance to the surrounding soil. The gage must either be directly coupled to the natural soil or the soil around the gage must be replaced in such a manner that the natural characteristics are identically reproduced, virtually an impossible task. Even if the gage is directly coupled to the natural soil the excavation must be refilled. Differences in the characteristics of the backfill and the natural soil deposit may influence the response of the soil in this region. Field tests conducted in a controlled area which is excavated and then backfilled still pose difficult problems. These tests are usually large scale and a mechanical method of compaction such as large rollers is used. If gage orientation or alignment is critical a special means of compaction probably will be required in the area of the gage. This introduces the problem of trying to duplicate on a small scale the compactive effort applied to the remainder of the test area. If the gage is inserted after preparation of the entire test site then the same problems exist as for in situ measurements. In laboratory studies most specimens are remolded and in such cases the gage may be embedded as the specimen is formed. However, some latitude must be provided in the required gage alignment in the soil and provision must be made for placement of the soil in the vicinity of the gage to ensure homogeneity throughout the entire specimen.

The requirements of measurement and operation which the gage must possess may be summarized as follows:

(1) accurate determination of gage length

(2) sensitivity to small changes in gage length

(3) insensitivity to effects of lateral and shearing strains

(4) small gage length

(5) wide range of frequency response

(6) small size

(7) offer no resistance to movement to actuate the gage

(8) density in the range of soils in which it is used

(9) tolerable requirements of alignment to allow placement

(10) permit placement of soil in gage vicinity.

3.2 Gage Design

The gage concept found to most satisfactorily meet the established criteria was the uncoupled strain gage. The gage consisted of two small coils of copper wire embedded in the soil with a second set of identical coils external to the soil, each set of coils representing a primary and secondary transformer winding. In this transformer configuration, the primary coils are series connected to an a-c power source, and the secondary coils are series connected to a receiving circuit. Each set of windings, when closely spaced, is linked by a magnetic field whose rate of change, because of the a-c excitation, induces an alternating voltage in the secondary winding. The magnitude of the induced voltage is a function of distance between windings, flux path permeability, strength of excitation and number of turns.

An initial experimental-circuitry setup (Figure 1) indicated that it was feasible to use this principle in the design of a soil strain gage. Two sets of coils are used to increase sensitivity to differential movements. This is necessary because the percentage voltage change measured across one sensor coil for small changes in spacing is small. However, with the two sets of coils connected so that the resulting signal is the difference of the individual coil outputs, the percentage change in output voltage is greatly increased. This voltage was amplified to increase sensitivity so that changes in spacing at least as small as 1 per cent of the nominal spacing could be detected. This arrangement is referred to as a null-balance system.

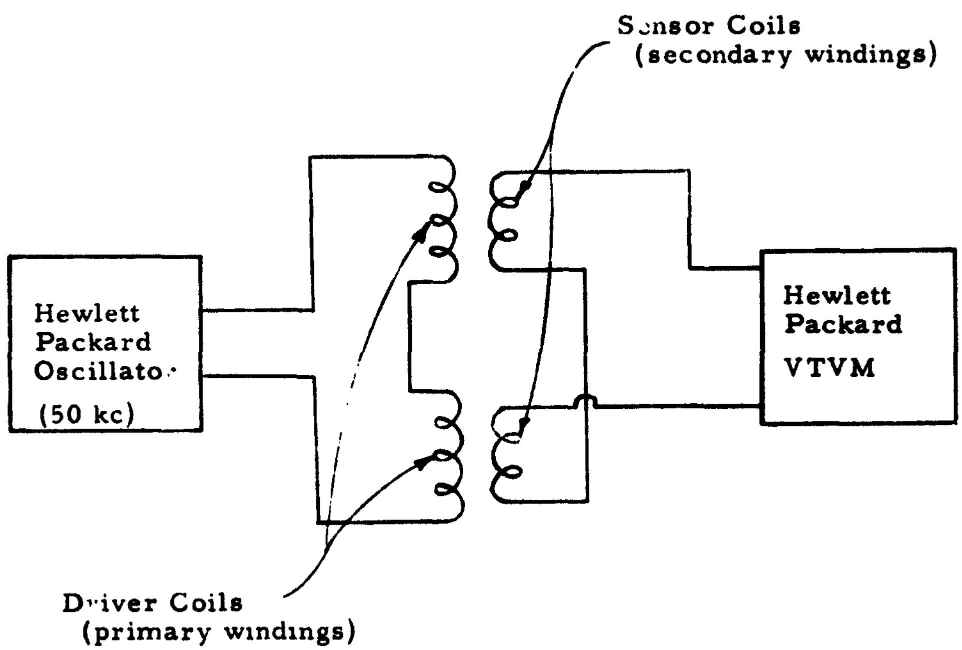


Fig. 1 STRAIN-GAGE CIRCUITRY

Figure 2 shows the basic components of the air-core differential-transformer setup for the application as a soil strain sensor. When the driver coils (primary windings) were energized with a high frequency a-c current, voltage was induced in the pickup coils (secondary windings). The spacing of the embedded coils was then determined by adjusting the external micrometer mounted coils until a null was obtained.

The accuracy with which gage length (initial coil spacing) can be determined (when perfect alignment conditions exist) depends on the uniformity of coil construction. If the driver coils were identical, then the magnetic fields generated would also be identical. Similarly if the pickup coils were identical, then the induced voltages would be identical for the same spacing. The best fitting was obtained by constructing a number of gages and checking them in pairs by trial and error. By this procedure it was possible to make the null spacings agree within 1 per cent over a minimum range of spacings of 0.2 in. to 0.5 in.

Perfect alignment conditions cannot, of course, be realized. This would impose too great restrictions on placement, and even if perfect initial alignment were possible, lateral and shearing strains might produce some lateral relative displacements. To reduce sensitivity of the device to small misalignments, the driver coils were made larger in diameter than the pickup coils. This was accomplished by winding the driver coils with a greater number of turns and a larger inside diameter. A ratio of two to one was used for both the number of turns and the inside coil diameter. This is contrary to efficient transformer design because induced voltage is directly proportional to the number of winding turns. However, in this manner the area of uniformity of the magnetic field created by the driver coil was greater than the cross sectional area of the pickup coil. This allowed the pickup coil to move laterally within this uniform area with negligable effect on gage output. The actual amount of movement allowed is dependent on the coil spacing and varies somewhat with the uniformity of coil construction.

Investigation of ID ratios of 4:1 showed slight improvement in performance, but it was decided the advantage gained was not great enough to justify the corresponding increase required in driver coil OD.

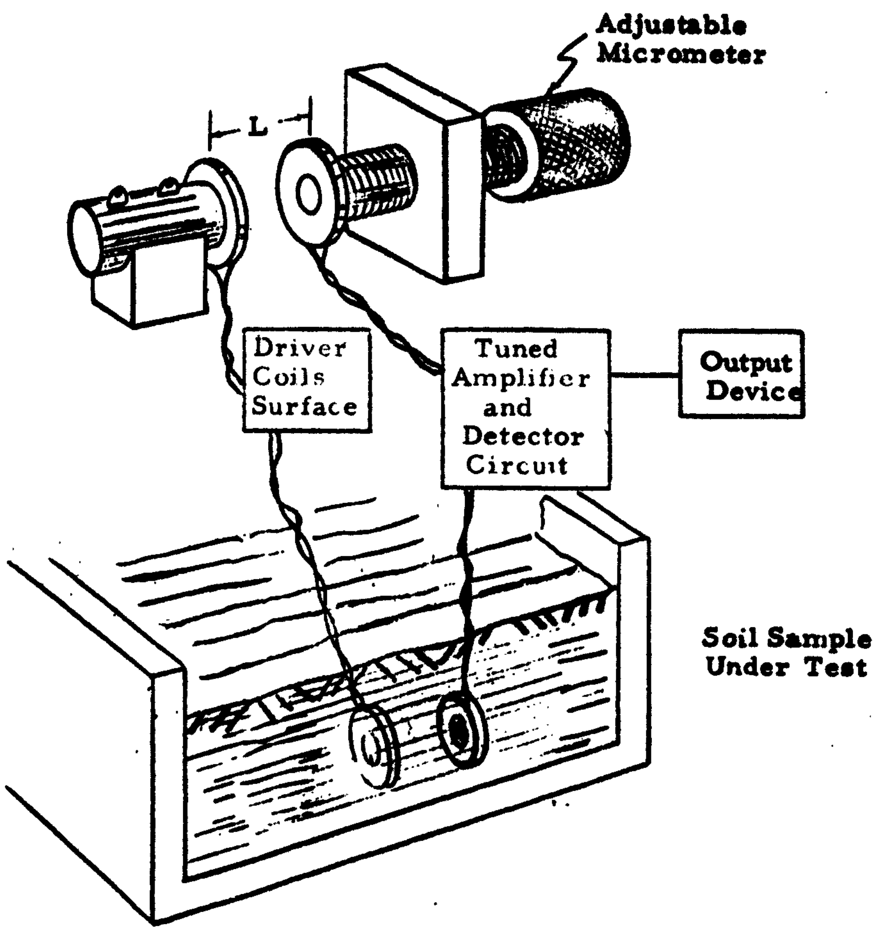


Fig. 2 PICTORIAL DIAGRAM OF SOIL STRAIN GAGE

Minimum coil size was dictated by considerations of sensitivity and the physical limitations on winding. Initially, coils were wound with 500 turns on the driver coils and 250 turns on the pickup coils. It was found that this could be reduced to 300 turns on the driver and 150 on the pickup without seriously impairing the sensitivity of the gage. Number 40 wire (Formvar Magnetic wire) was considered the smallest size practical to work with. As technique in working with the wire and winding coils improved, it became possible to wind the coils to a thickness of 1/32 in. These coils were then molded in an epoxy which served as insulation against moisture and contributed the necessary sturdiness. A covering of 1/64 in. was provided on each side of the coil, making the total encapsulated coil thickness 1/16 in. The outside diameter of the coils was made 3/4 in. to accomodate the required number of driver coil windings and to allow the lead connections to be encapsulated.

The density of the coils, as constructed, was approximately 120 lb per cu ft. This is in the range of most soils and in this respect is considered to be quite satisfactory.

While the coils, differentially connected, represent the basic elements of the gage, electronic circuits to amplify, demodulate, indicate signal levels and maximize sensitivity, as well as the adjustable precision coil mount are necessary parts of the gage apparatus and had to be designed specifically for this system.

The strain-gage electronic components consist of a crystal controlled 50-kc oscillator and drive-coil power amplifier. The pickup coils are connected to an amplifier, which in turn is connected to a ring demodulator, filter, and meter. The 50-kc oscillator is a standard component manufactured by Delta-F of Geneva, Illinois. The unit is powered by a Dessen-Barnes 30-volt, 325-milliampere power supply.

Figure 3 is a circuit diagram of the complete system. The 50-kc Delta-F oscillator has an output of approximately one volt at 600 ohms. This signal is amplified by transistor Q 1 to a level of approximately 10 volts measured at the output of the 10-turn winding of the transformer T1 to which

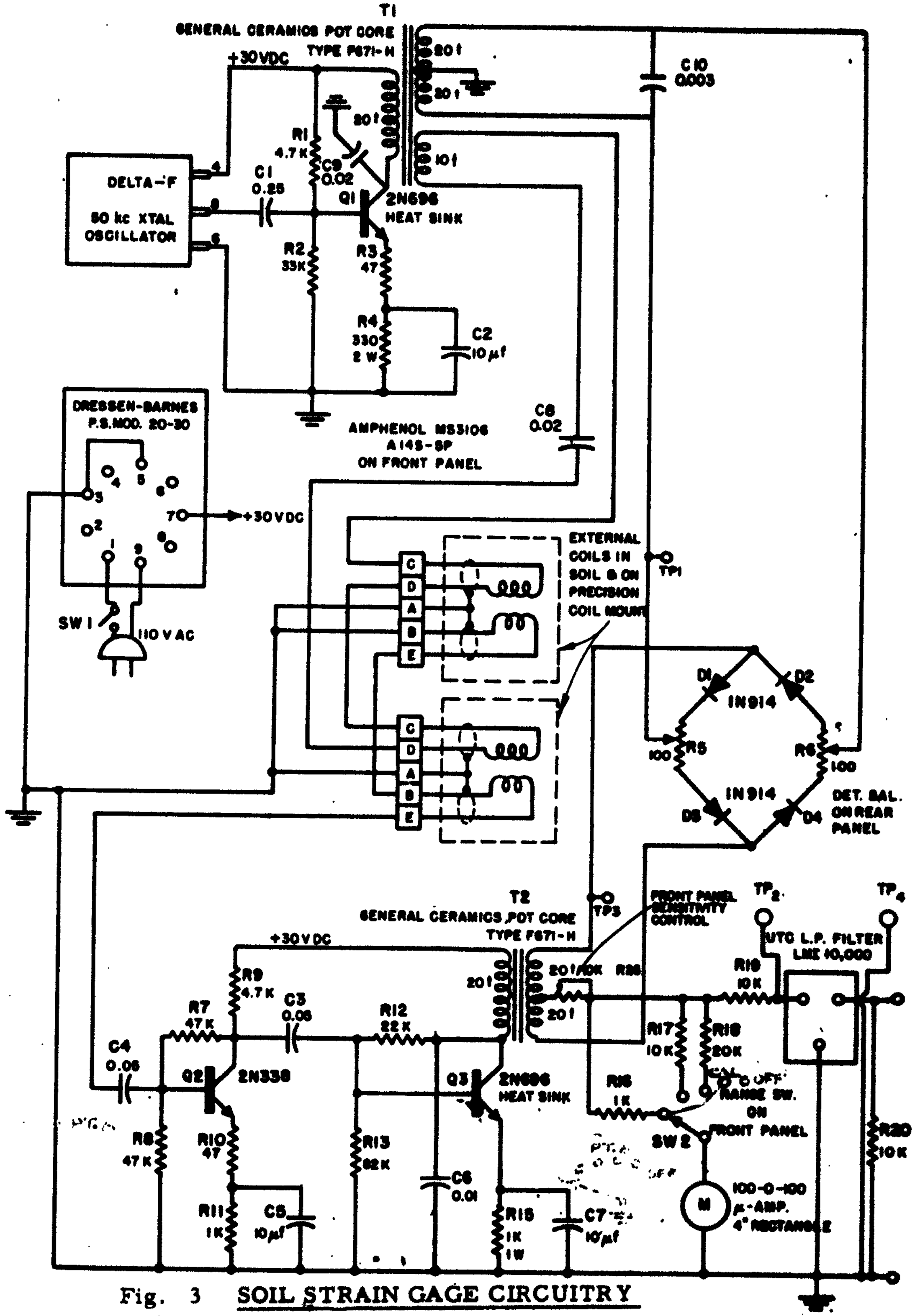


Fig. 3 SOIL STRAIN GAGE CIRCUITRY

the driver coils are connected. The pickup coils are connected differentially so that for equal spacing between the two sets of sensor and driver coils the resultant output is zero. When the spacing of the two sets is different, a small differential voltage appears at the input of the amplifier. Once amplified, the signal of interest is the envelope of this high-frequency carrier, since it is this amplitude which is proportional to the coil spacing. To separate the envelope from the high frequency carrier, the signal must be demodulated A conventional ring demodulator was used. This type demodulator is sometimes called a synchronous detector and permits operation with a suppressed carrier. The demodulator output, therefore, is zero when the carrier input is zero or nulled, and is either positive or negative in polarity when the two sensor coil voltages are not equal. The polarity depends on which coil has the larger voltage, thereby indicating whether the coils which would be embedded in the sample have moved closer together or farther apart. The maximum signal level with one set of coils placed close together and the others set far apart is 20-v peak-to-peak measured across TP1 on the rear of the unit. The capacitors, C6 in the collector circuit of the second amplifier Q3 and C7 in the driver coil circuit provide filtering of harmonics and correct phase error. The response of the electronics is restricted to 10-kc by the output filter which follows the demodulator circuit. A meter is provided for accurate nulling along with sensitivity range controls.

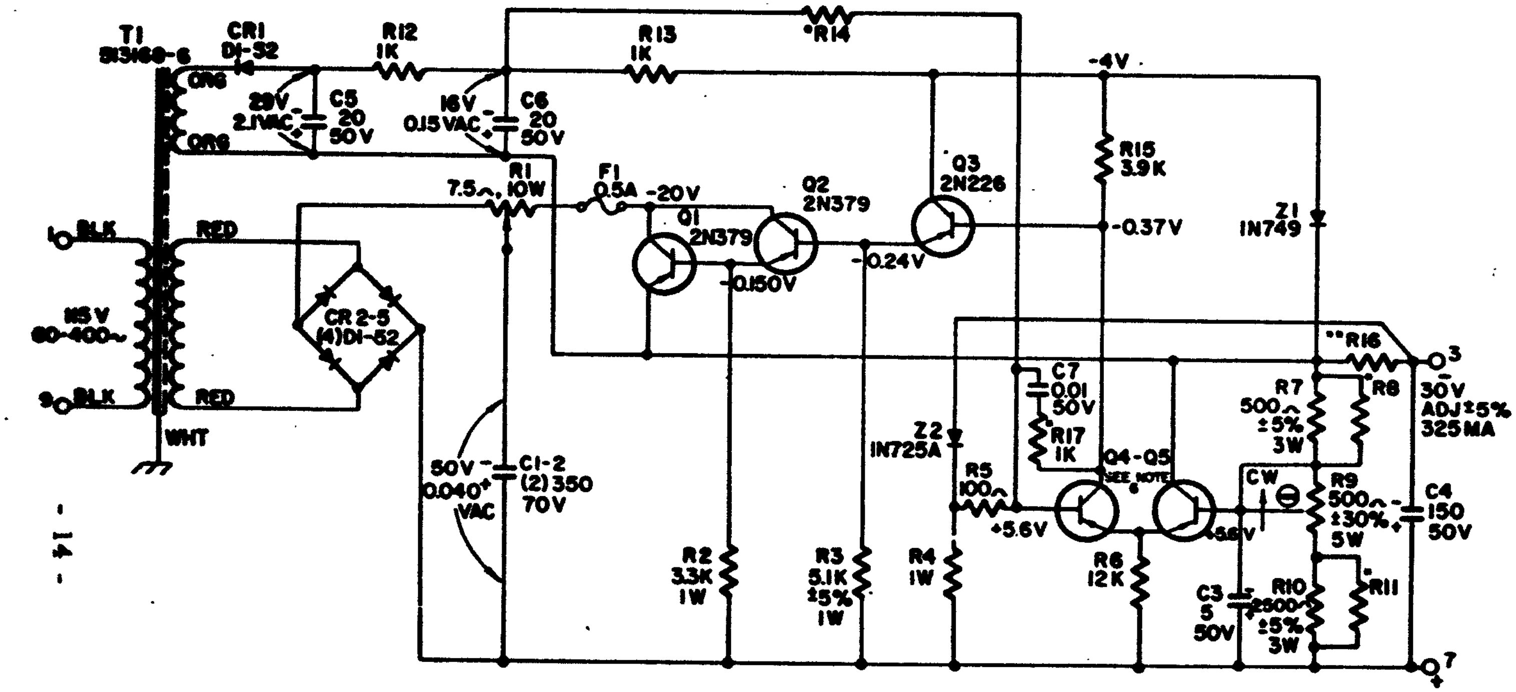
A Dressen-Barnes Model 20-30 transistor power supply is built into the instrumentation package. A circuit diagram of the supply is shown on Figure 4.

The shock-front rise time which the gage can sense is governed by the reaction time of the entire circuitry. The oscillator produces a 50-kc signal and theoretically the gage should sense a shock rise time of 20 μ sec. However, lag is introduced throughout the circuitry as each component functions. The reaction time of this system as a whole is of the order of 75 μ sec. This is felt to be suitable for most applications.

POWER SUPPLY MODEL 20-30

A-3. CIRCUIT SCHEMATIC

MANUFACTURED BY DRESSEN-BARNES ELECTRONICS CORPORATION



NOTES:

1. Conditions for test voltage measurements:
   a. Input set at 115 volts, 60 cps.
   b. Output set at 30 volts, with zero load.
   c. All voltages are DC, unless otherwise indicated.
   d. All voltages measured with a vacuum tube voltmeter.
   e. All voltages measured with respect to the negative output terminal, unless otherwise indicated.
   f. All test voltages indicated are approximate.
2. All resistors are 0.5 watt, unless otherwise indicated.
3. All resistors are 10% unless otherwise indicated.
4. * Indicates calibration components, which may vary among individual units.
5. Capacitance is in microfarads.
6. Q4 and Q5 matched pair of 2N226 transistors, order as a single 2N227.
7. ** Load compensation wire, calibration adjustment.

CAUTION: The above schematic illustrates connections for an unmodified solder terminal unit. Terminal and pin connections for modified units are listed below.

OCTAL PLUG PIN CONNECTIONS

Modification Code	AC Input		DC Output +	DC Output -	Remote Sensing +	Remote Sensing -	Remote Voltage Adjust		Remote Fuse		Ground
M1 & M01	7	8	6	3	-	-	-	-	-	-	-
M2 & M02	7	8	6	3	2	1	-	-	-	-	-
M3 & M03	7	8	6	3	-	-	4	5	-	-	-
M4 & M04	7	8	6	3	-	-	-	-	1	2	-
M5 & M05	7	8	6	3	2	1	4	5	-	-	-
M6 & M06	7	8	6	3	2	1	-	-	4	5	-
M7 & M07	7	8	6	3	-	-	4	5	1	2	-

SOLDER TERMINAL CONNECTIONS

Modification Code	AC Input		DC Output +	DC Output -	Remote Sensing +	Remote Sensing -	Remote Voltage Adjust		Remote Fuse		Ground
MT2 & MT02	1	9	7	3	6	4	-	-	-	-	5
MT3 & MT03	1	9	7	3	-	-	2	8	-	-	5
MT4 & MT04	1	9	7	3	-	-	-	-	4	6	5
MT5 & MT05	1	9	7	3	6	4	2	8	-	-	5
MT6 & MT06	1	9	7	3	6	4	-	-	2	8	5
MT7 & MT07	1	9	7	3	-	-	2	8	4	6	5
MT8	1	9	7	3	-	-	-	-	-	-	5

Fig. 4 POWER SUPPLY USED IN SOIL STRAIN GAGE ELECTRONICS

Figure 5 displays the components which constitute the soil strain gage in its finalized form. These consist of two sets of coils, the adjustable precision coil mount, and the electronic auxiliaries.

Conventional trouble-shooting techniques should be employed in servicing this instrument. For aid in servicing and maintaining the instrument the following information is included in Appendix I: Component parts listing (Table I-1), Component parts location (Fig. I-1), the Dressen-Barnes parts list (Table I-2), and the Dressen-Barnes power supply manual.

3.3 Operational Procedure

There are four controls on the soil strain gage instrumentation package. Three are on the front panel and the other is accessable from the side of the instrument. The following procedure should be followed in alignment of the instrument to assure accuracy:

(1.) Place both sets of coils on adjustable micrometer coil mounts The rods on which the coils are mounted are nonmetallic to avoid any distortion of the magnetic field. The micrometer head provides mechanical means of accurate adjustment of coil spacing.

(2.) Before the instrument power is turned on observe the meter reading. If the meter reads off the zero mark, adjust the meter zero adjustment control to obtain a zero reading.

(3.) Turn on power.

(4.) Allow unit a minimum of 15 minutes warm up time to reach a stable operating temperature. Place the range selector to the calibrate position and observe the meter reading. If the null meter does not read zero connect a CRO or an a-c voltmeter to TP-2 (on the rear of the instrument) and ground, and observe the voltage level Adjust the demodulator balance controls (on the side panel) to obtain a d-c null and a minimum a-c level. If the meter reads only slightly off null, a-c level may be neglected and adjustment of one of the demodulator balance controls to obtain null is sufficient. The adjustment should be checked periodically during testing.

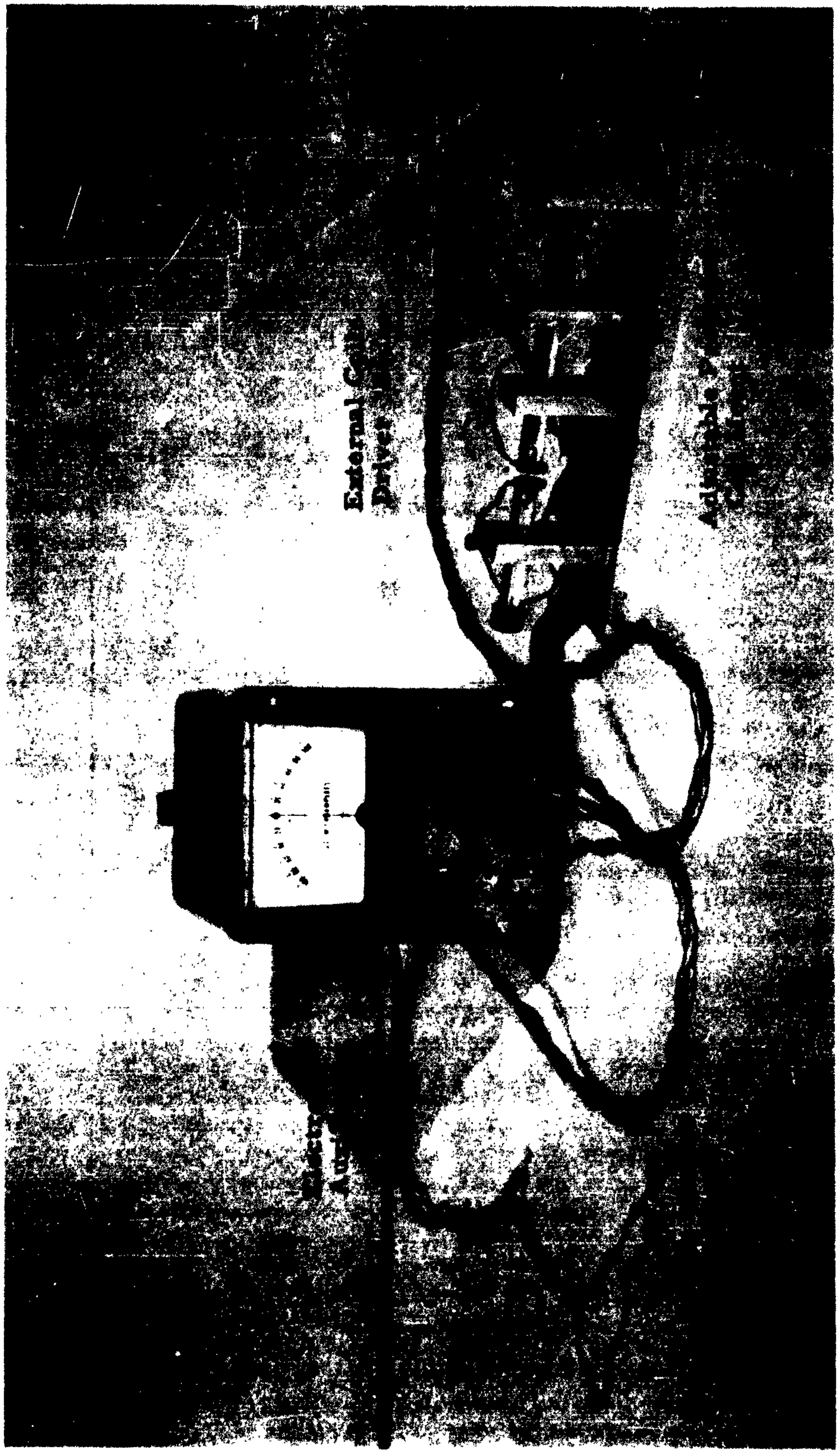


Fig. 5 SOIL STRAIN GAGE

(5) Adjust the micrometer coil mounts so that both coils are spaced at about 0.4 in. (or approximately the expected embedded spacing). Place the range selector switch on low sensitivity. If the meter moves far off null, and there is little or no effect by adjustment of the micrometer, the coils are differentially connected and one coil connection must be reversed. If coil connections are reversed, recheck null in the calibrate position as null may change slightly. With coil connections properly established, move the range selector switch to high sensitivity and adjust both micrometers to the same setting. Release the set screw locking the stationary coil position (on the coil set which is to serve as the external reference coils). Adjust this stationary coil position to obtain null, and lock the stationary coil in position. This compensates for nonuniformities which may exist in the generated magnetic field at approximately the expected test spacing, and also for any difference in the thickness of the coil epoxy coating.

(6) The range selector switch should now be placed in the off position. The coils which are to serve as the embedded sensing elements may be removed from the micrometer mount and inserted in the test specimen.

Note: Do not remove the coils from the micrometer mount with the range selector switch on high or medium sensitivity positions or the resulting rapid off-scale indicator movement may damage the meter

Upon completion of specimen preparation the range selector switch should be set to low sensitivity and the externally mounted coils adjusted by the micrometer screw to obtain a null at the indicator. The next procedure depends on whether the imposed loading on the specimen is to be static or dynamic

For static measurements the following procedure is recommended: Set the range selector switch to high sensitivity. This makes the gage sensitive to differential movements of the order of 0.3 per cent of the coil spacing. As the specimen is deformed, continually renull using the micrometer head to reposition the externally mounted coils. The spacing of these coils will then follow the spacing of the embedded coils.

For dynamic measurements a different procedure must be used since it is not possible to continually renull. In this case, it is first necessary to estimate the maximum change which will occur in coil spacing. The externally mounted coils are then offset by this amount and the sensitivity controls adjusted to give maximum sensitivity without overdriving the amplifier. Gage output is also fed to an oscilloscope where sensitivity controls again must be adjusted to maintain the signal on the scope over the entire range of movement expected. With both strain gage and scope sensitivities set, the gages are then calibrated. This is done by moving the externally mounted coils through a series of incremental changes and noting the corresponding signal displacement on the oscilloscope. These displacements are of opposite phase but equal magnitude to those which are caused by identical differential movements of the embedded coils under an applied dynamic load.

The following procedure is suggested for oscilloscope calibration:

(1.) The oscilloscope selected should have a d-c vertical amplifier.

(2.) Make an estimate of the maximum coil spacing change expected. With the scope set to sweep repetitively at some reasonable rate (0.5 or 0.1 milliseconds per division) null the output by observing the meter.

(3.) Set this line at the top of the scope face.

(4.) Separate the coils on the precision coil mount, from the null position to the distance estimated in step 2.

(5.) Adjust the gain of the scope so that this level is represented by the sweep line near the bottom of the scope face.

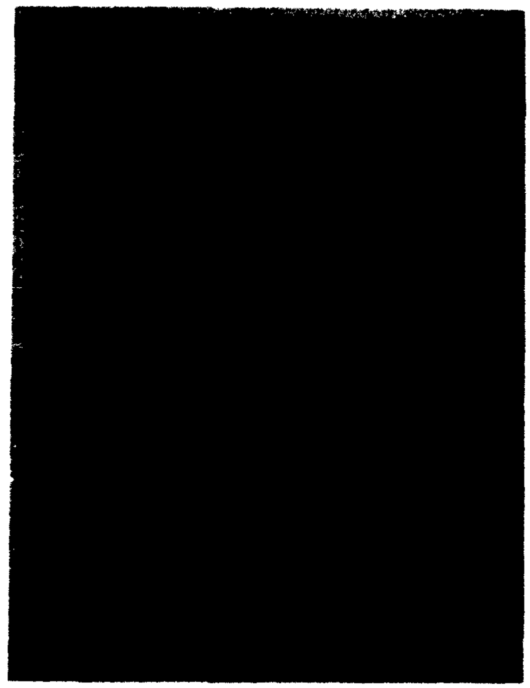
(6.) Return to null and photograph that line.

(7.) Photograph a line spaced a desired distance down (such a 1 cm from the null line or that which would be produced by adjusting the coils 0.005, 0.010, or 0.020 in. further apart from null). Photograph a series of sweeps in equal increments, and then return to null.

(8.) Adjust scope sweep rate to that estimated to be appropriate for the test.

(9.) Adjust the scope sensitivity so that only one complete sweep will appear during the test. The instrument is now ready to record the transient strain pulse. Figure 6 is an example of how the calibrated scope face would appear in the photograph.

A complete operation manual will be issued with the soil strain gage for convenience in maintaining and operating the equipment.



20 mil

5 mil
divisions

Coil Spacing 0. 35 inch

Fig. 6 <u>CALIBRATED SCOPE RECORD</u>

4. EVALUATION OF GAGE PERFORMANCE

4.1 Bench Evaluation of Gage Performance

The principle of operation of the soil strain gage relies on the exact uniformity of the magnetic fields between the two sets of coils; one set placed in the soil, the other placed on a precision-adjustable coil mount. Because the lines of flux of the magnetic field are influenced by the permeability of the medium in which they exist, the initial investigation examined the possible effect of soil and moisture upon the magnetic field of the embedded coils. Sand, kaolinite clay, illite clay, and bentonite were used for this investigation. Both sets of coils were placed on the precision mounts and adjusted to a null position. Each soil in the air-dry state was then placed in turn around one set of coils, and the coils renulled at various gage spacings. In no case was the accuracy of null affected by the presence of the soil. The procedure was then repeated with water added to the soil; again no effect could be detected on the null position.

One set of gages was then immersed in water to ensure that adequate protection against moisture was being provided by the epoxy coating, and to determine if the difference in flux permeability between air and water affected the performance of the gage. Again no effect could be detected.

A soil containing iron might be, it was thought, the worst condition in this respect. To check this the gage was embedded in dry kaolinite clay containing iron powder. Mixtures of 2 per cent and 4 per cent of iron powder by weight were placed around one set of coils.

The results of this investigation are presented in Figure 7. Per cent error in spacing is based on the true spacing of the coils surrounded with soil. Disagreement in coil spacing in air (without soil surrounding either gage) is due to slight nonuniformities in coil construction, as seen it is only 1 per cent at 0.2-in. spacing and within 0.5 per cent from 0.3-in. to 0.6-in. spacing. The addition of 2 per cent iron powder has no effect. The difference in this curve and that for air is within the capability of determining null. The addition of 4 per cent iron powder results in a curve

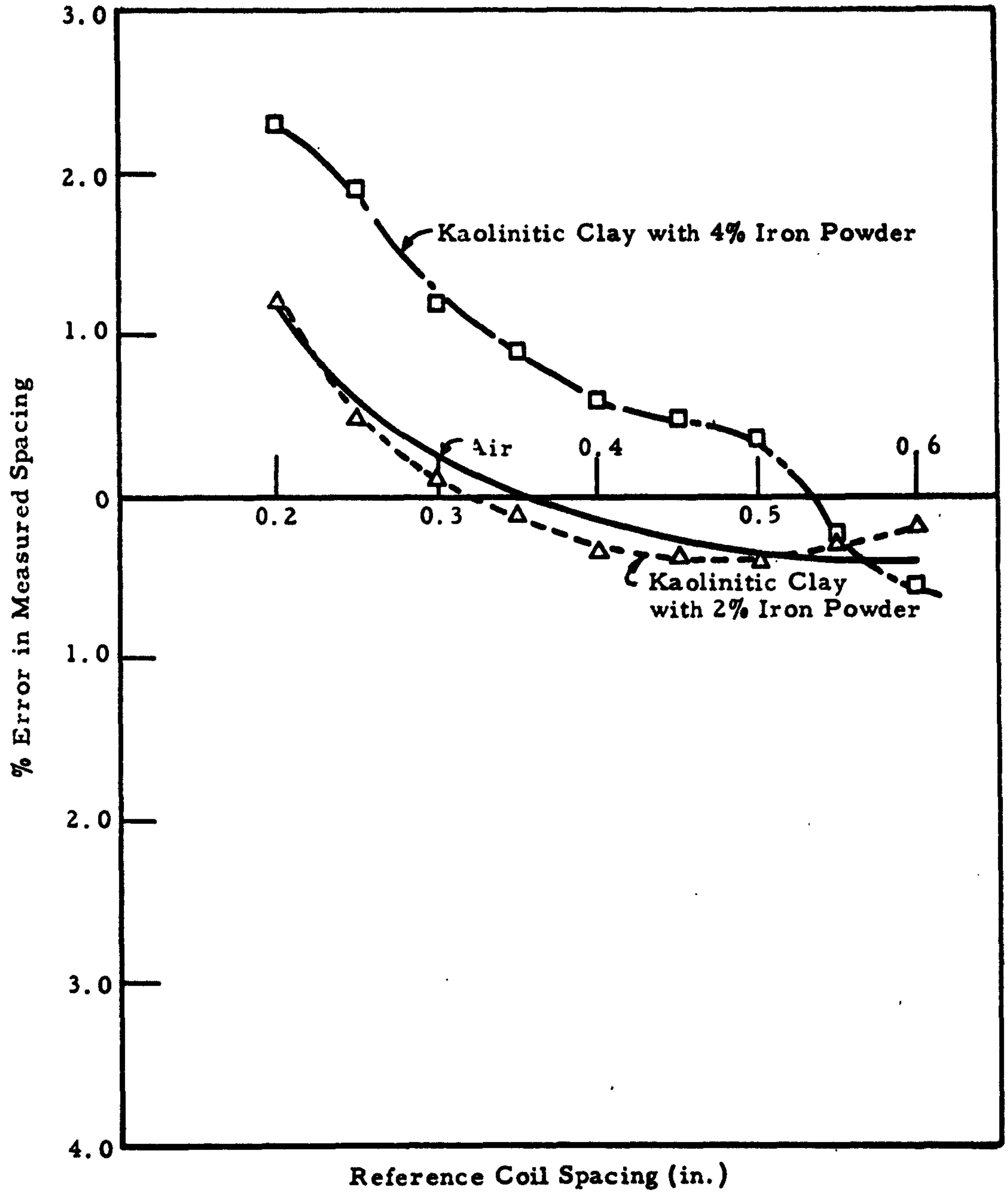


Fig. 7 EFFECT OF SOIL WITH MAGNETIC MINERAL CONTENT ON GAGE PERFORMANCE

almost identical to the first two, out to a spacing 0.5-in., except that it is shifted upwards about 1 per cent. Beyond 0.5-in. sensitivity diminishes rapidly and the reliability of the gage is considered to be questionable. Four per cent magnetic mineral content is considered to be as high a percentage as would normally be found in soils. If a soil with higher magnetic-mineral content were encountered, compensation could be made by inserting soil of the same type between the reference coils. If identical conditions were produced in the spacing between the embedded coils and reference coils, this source of error would be eliminated.

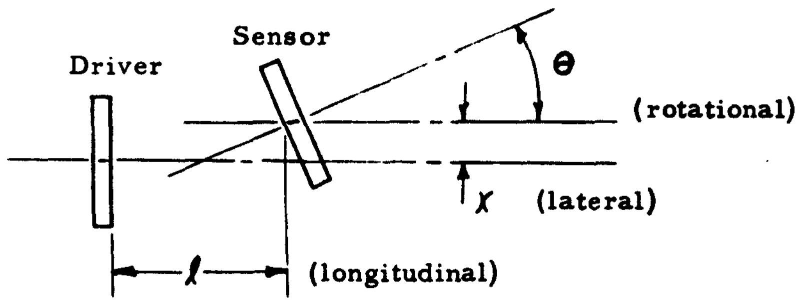


Fig. 8 COIL POSITION PARAMETERS

The effect of lateral and rotational misalignment was next investigated (Figure 8). To examine these effects one set of coils was positioned on a machinists jig to allow lateral and rotational movements. The other set was positioned on the micrometer mount. The system was energized and the coils nulled at a spacing of 0.100 in. The coils on the micrometer mount were then displaced 0.001 in. and the differential voltage recorded. The system was then renulled and the coils on the jig laterally displaced until the same differential voltage was generated. This displace- is the amount of lateral misalignment which will cause a 1 per cent error in the determination of gage spacing. Lateral displacements required to produce 2 per cent and 3 per cent error in spacing were similarly determined. The coils were then realigned laterally and the rotation which caused the differential voltage for 1 per cent change in spacing to be generated was determined. This procedure was then repeated at coil spacings of 0.2, 0.3, 0.4, and 0.5 in. Table 1 summarizes these results.

TABLE 1

COIL MISALIGNMENT FOR PERCENTAGE ERROR IN DETERMINATION OF COIL SPACING

Gage Spacing, ℓ (in.)	Lateral Misalignment, (in.)			Rotational Misalignment, (deg)
	Per Cent Error			
	1%	2%	3%	1%
0.1000	± 0.020	± 0.030	± 0.036	± 5
0.2000	± 0.032	± 0.045	± 0.060	± 8
0.3000	± 0.040	± 0.058	± 0.072	± 8.5
0.4000	± 0.050	± 0.068	± 0.082	± 9
0.5000	± 0.060	± 0.078	± 0.090	± 11

The performance of the gage with respect to rotational misalignment is felt to be adequate. Experience gained in working with the gage has shown that there is sufficient latitude tolerable to allow for proper placement.

Lateral misalignment is more of a problem with respect to placement. While the gage is much less sensitive to lateral motion than to axial motion, the lateral motion required to produce 1 per cent error in the nulled spacing is of significant magnitude with respect to percentage of spacing distance (approximately 15 per cent at 0.2 in. spacing and 12 per cent at 0.5 in. spacing). In terms of actual distance this allows only 0.06 in. at 0.5 in. spacing, implying rather stringent requirements on placement of the coils, especially if some method of physical disturbance is used to compact the specimen.

The effect of initial misalignment upon determination of incremental change was also investigated. For static measurements this effect can be seen from the data in Table 1, (since statically one continually renulls the system to determine the change in coil spacing). For example, if the coils were misaligned 0.06 in. laterally at 0.500 in. spacing, the expected per cent error in determination of spacing would be 1 per cent. Movement of the coils inward to 0.2000 in. spacing without further increase in misalignment would increase this error in determination of spacing to only 3 per cent. Dynamic measurements, however, rely on monitoring the differential voltage generated when the coils are displaced from the null position. Measurements were made to determine if any significant difference in the generated output for a given differential displacement of the coils from null occurs with the coils aligned versus misaligned.

The procedure followed was to null the gages when aligned, and then axially to displace the reference coils on the precision mount 1 per cent of their spacing. The coils were renulled by laterally misaligning the other coils. The reference coils were then moved through a series of incremental changes over a range of ± 20 per cent of the coil spacing and meter output determined. The system was then renulled and the incremental changes in spacing of the misaligned coils to produce these same meter readings determined. This procedure was then repeated for rotational misalignment. Figures 9, 10, 11, and 12 show the results obtained for spacings of 0.3 and 0.5 in.

Figure 9 presents the data for lateral misalignment at 0.3 in. spacing. As seen, the output for both coils is identical for movement of the coils together, which simulates compression of the specimen. For outward coil movements, simulated tension, the greatest difference in gage spacing for the same generated differential voltage is 0.002 in. occurring from about 0.03 in. to 0.04 in. incremental change. This represents a maximum error of 7 per cent in the determination of incremental change at about 10 per cent tensile strain.

Figure 10 shows the data for rotational misalignment at 0.3 in. spacing. The curves are virtually identical to those for lateral misalignment and the same comments apply.

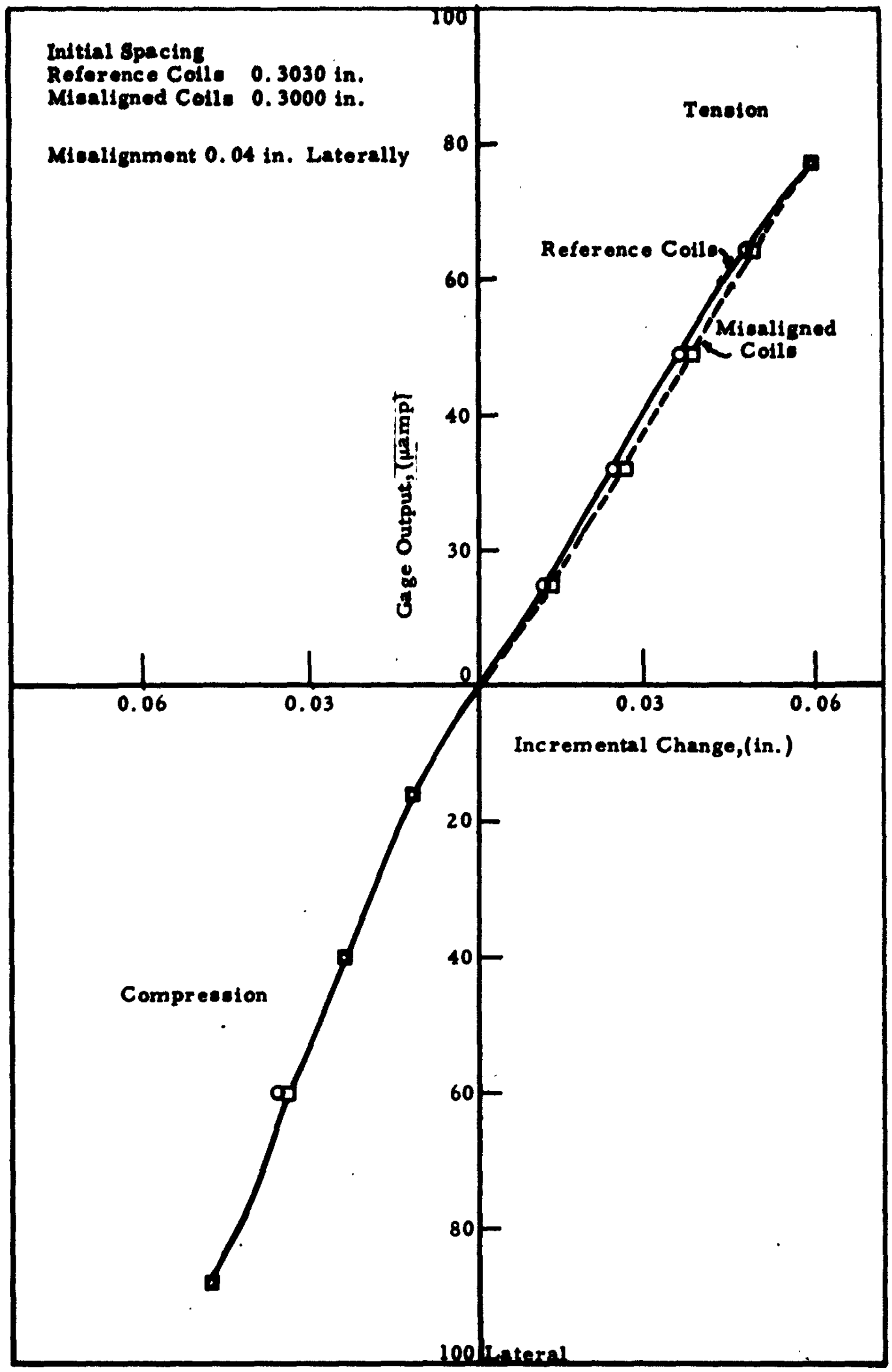


Fig. 9 EFFECT OF LATERAL MISALIGNMENT OF DYNAMIC CALIBRATION FOR 0.3-IN. COIL SPACING

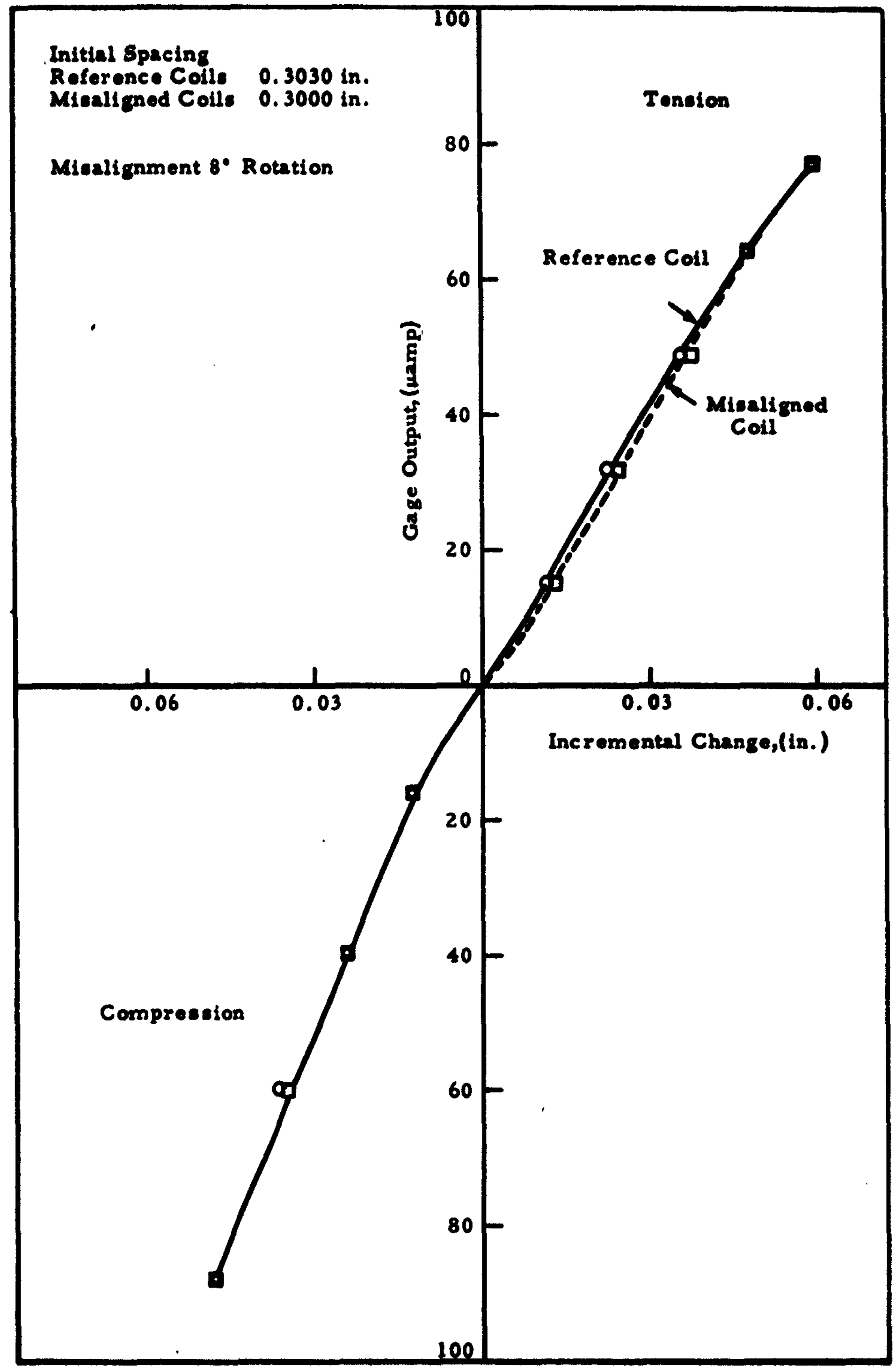


Fig. 10 EFFECT OF ROTATIONAL MISALIGNMENT ON DYNAMIC CALIBRATION FOR 0.3-IN. COIL SPACING

Figure 11 shows data for lateral misalignment at 0.5 in. spacing. The variance in the curves in the compressive direction represents an error in determination of incremental change which gradually increases from zero to 0.001 in. at 0.02 in. incremental change, or approximately 5 per cent error at 4 per cent strain. This per cent error then remains constant throughout the entire range of gage sensitivity. For outward movement of the coils the error increases gradually to approximately 10 per cent at 4 per cent strain. Again it then remains almost constant throughout the range of gage sensitivity.

Figure 12 is for rotational misalignment of the coils at 0.5 in. spacing. Correlation is much better in this case with essentially no error for compressive movement of the gage up to approximately 12 per cent strain. The error then increased to about 5 per cent at the ultimate range of gage sensitivity. In tension there was essentially no error up to 4 per cent strain. Beyond this, an error of approximately 5 per cent was found.

The above performance of the gage is felt to be satisfactory. It is unlikely that strains greater than 4 or 5 per cent will be encountered with soil in tension. Ten per cent is probably maximum in compression under dynamic load.

4.2 Static Evaluation of Gage Performance in Soil

Evaluation of the gage under static loads was undertaken to determine (1) the ability to consistently place the coils within the design tolerances of lateral and rotational alignment, (2) the effects of lateral and shearing strains which would tend to create further misalignment of the coils, and (3) the effect of gage presence upon the induced strain field.

It was not felt that all these effects could be adequately studied in this program. A thorough investigation of the effect of gage presence would require comparison of relative gage size in a controlled test series. A range in gage sizes was not available and since the gage was in the developmental stage, initial study had to be restricted largely to the first two effects. It was decided, therefore, to conduct a simple test in which these effects could be properly evaluated and at the same time some feeling for the effect of gage presence could be obtained.

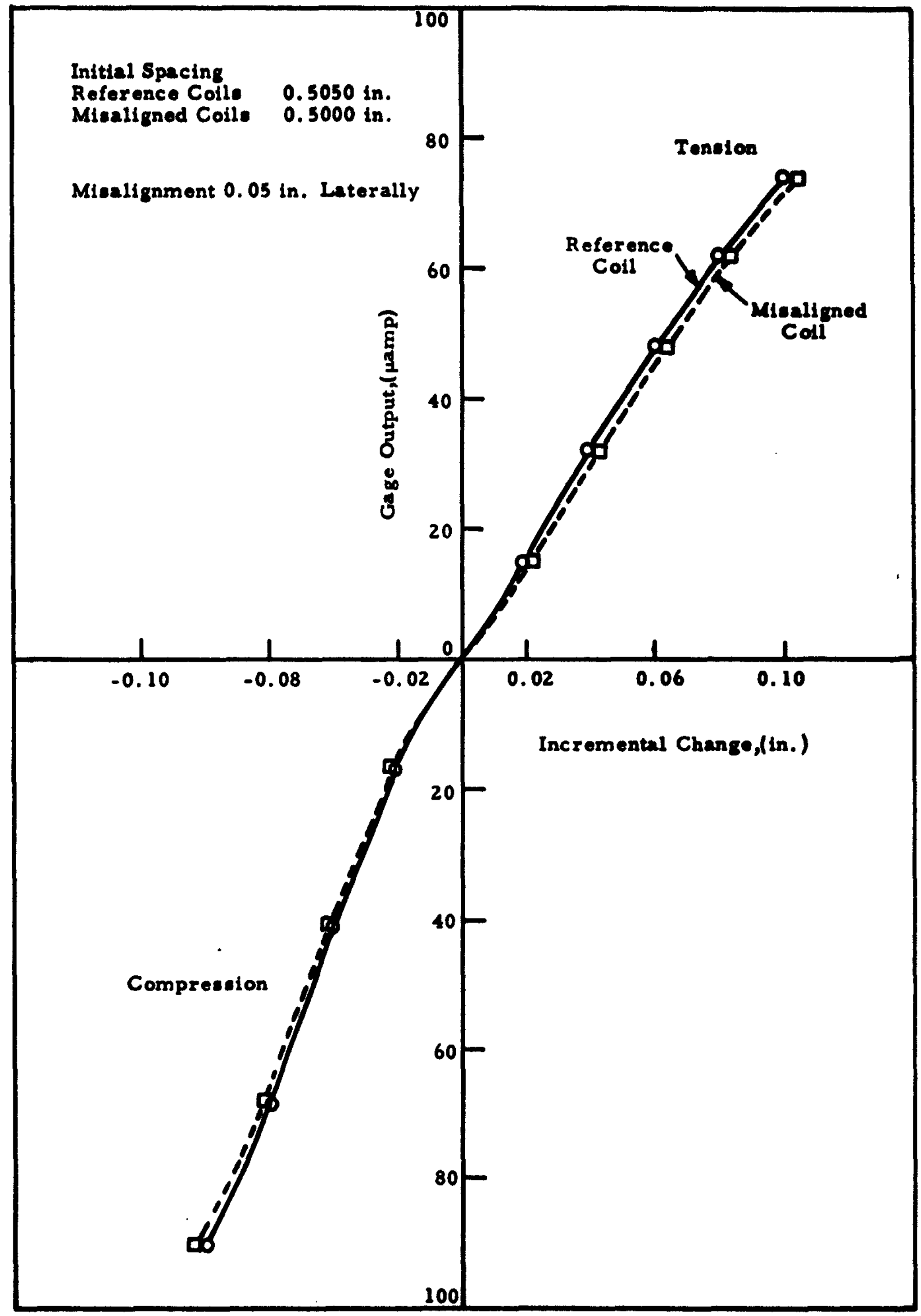


Fig. 11 EFFECT OF LATERAL MISALIGNMENT ON DYNAMIC CALIBRATION FOR 0.5-IN. COIL SPACING

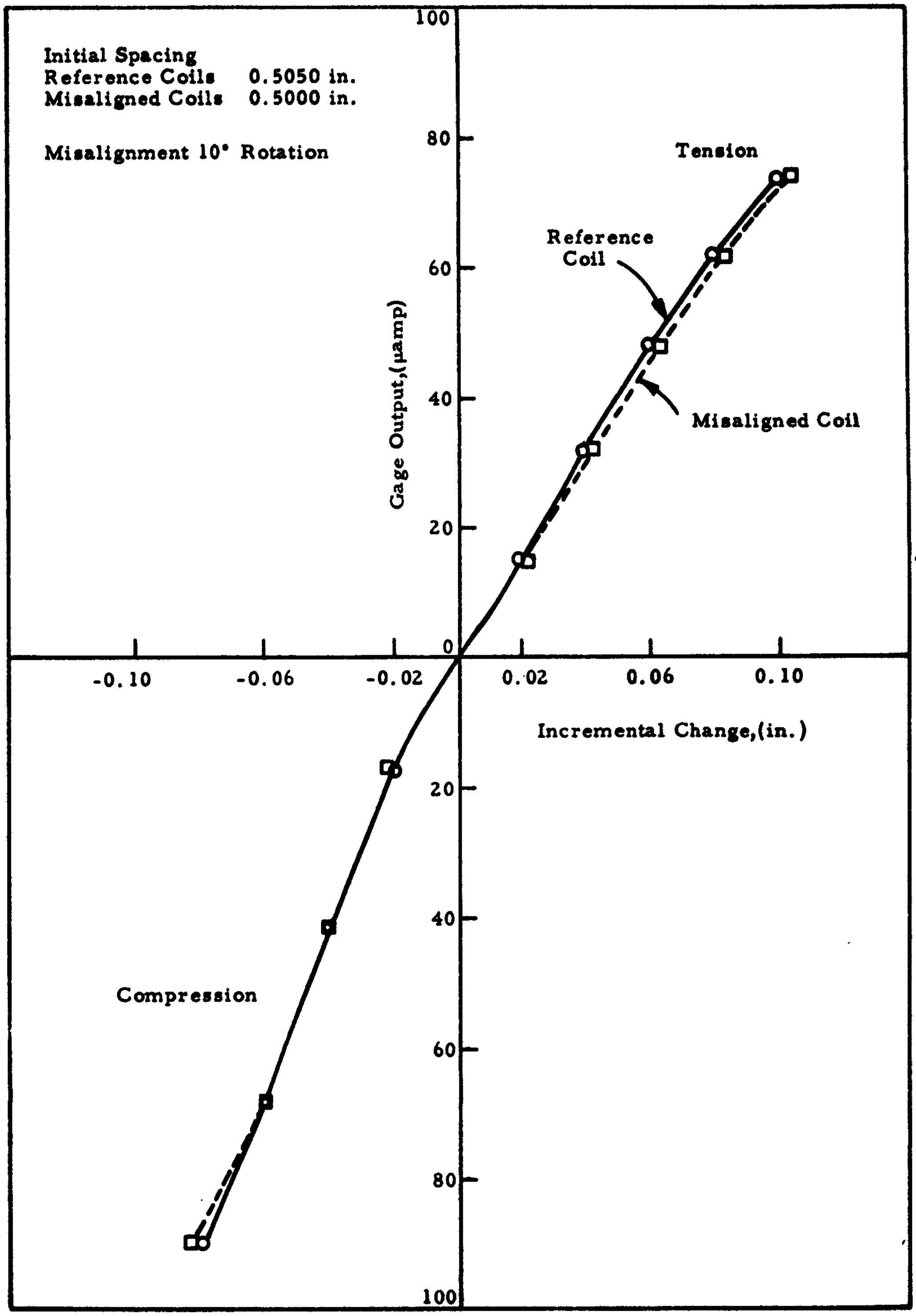


Fig. 12 EFFECT OF ROTATIONAL MISALIGNMENT ON DYNAMIC CALIBRATION AT 0.5-IN. COIL SPACING

The test selected was the unconfined compression test using cylindrical specimens of kaolinite clay. A range of moisture content was used to investigate the effects of varying soil stiffness. Figure 13 lists the characteristics of the kaolinite clay and shows the unconfined compression load-deformation curves for the extremes of water contents used. These data indicate the range in soil stiffness examined. Because the testing procedure followed was directed towards strain comparison, complete load-deformation records were not obtained for every test.

By using a clay as the test medium, a check could be made of misalignment introduced in placement and any further misalignment produced by straining the specimen by carefully slicing through a tested specimen to expose the coils and then mechanically measuring the gage spacing. This was then compared with the final position as determined by gage output.

Investigation of gage effect was limited to a comparison of gage-computed strain with average strain computed from total deformation of the specimen and with strain computed from surface measurements. These surface measurements were used to compute strain graphically in the following manner. The original position of horizontal lines marked at intervals longitudinally on the specimen, as measured from a stationary reference point, were laid off as the abscissa. The measured absolute movement of each line was plotted as the ordinate. The slope of the obtained plot is the strain. As such, it was thought that a uniform strain field might be generated in the specimen up to 3 to 4 per cent strain. However, this was definitely not the case. Although these comparisons cannot indicate the degree to which the presence of the gage influences soil response, they do provide some estimate of the significance of this effect. Tests were conducted with two coil sizes. The first coils developed for the project were 0.15-in. thick by 1-in. diameter. The final coils were 1/16-in. thick by 3/4-in. diameter.

The procedure used was as follows: remolded specimens were prepared in molds 2.8 in. diameter, 4-in. high and 2.8-in. diameter, 6-in. high which were lightly coated with grease to facilitate specimen removal. The clay was compacted in layers using a Harvard Miniature compaction tamper. The gage was inserted in the specimen at approximately mid-height during

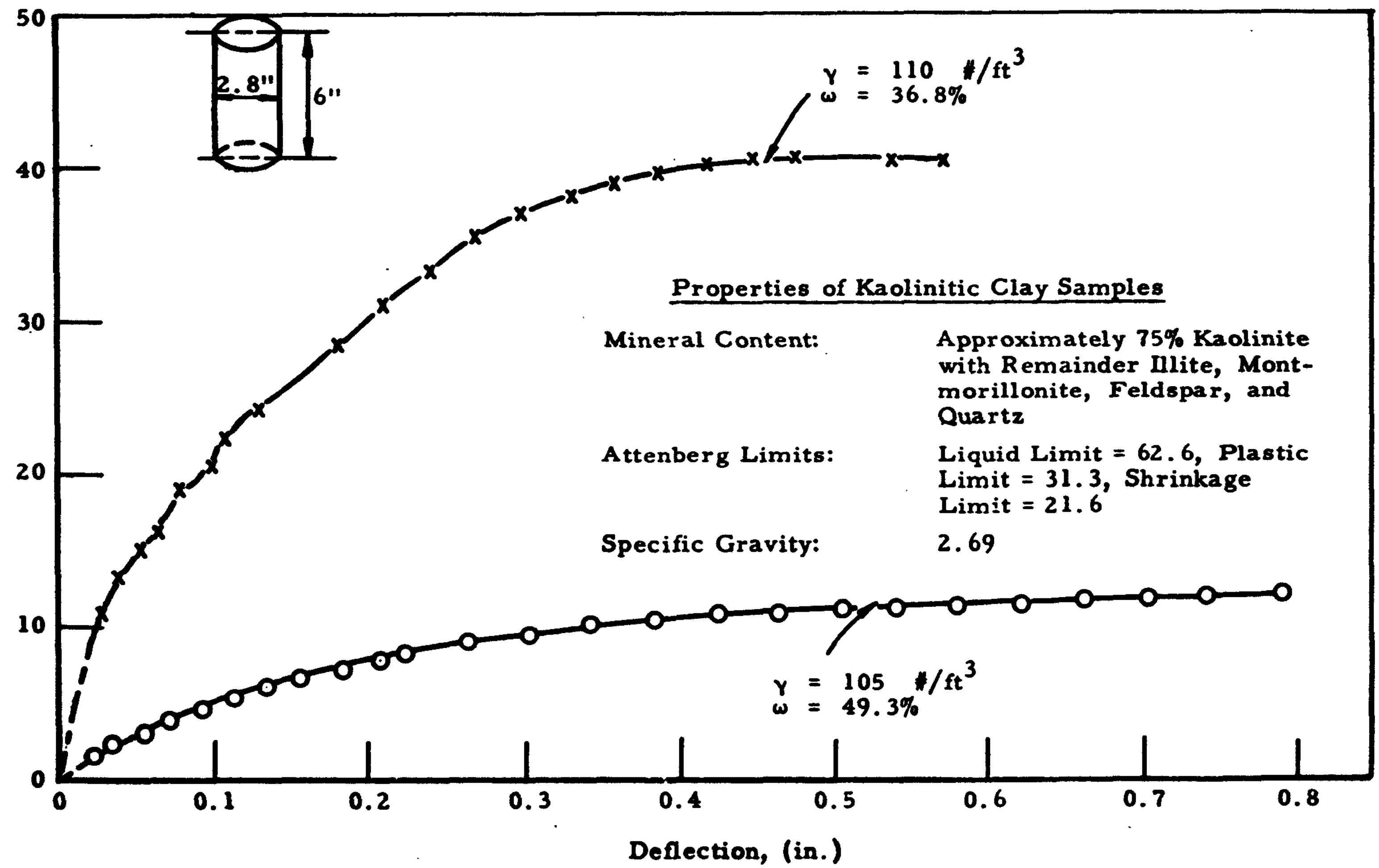


Fig. 13 UNCONFINED COMPRESSION LOAD-DEFLECTION CURVES FOR KAOLINITIC CLAY

preparation. Tests were conducted with the gage embedded at the axial center and at the periphery of the specimen. It was found necessary to stabilize the relative coil position while the soil was being compacted to maintain proper coil alignment. This was accomplished by inserting a 1/16 in. diameter rod through the center of the two coils. The rod was withdrawn after completion of the specimen. After the specimen was removed from the mold, a knife edge was used to score the surface horizontally at intervals, to provide a means for measuring surface strains.

The specimens were then tested in unconfined compression; total specimen deformation was recorded by means of a dial gage. The method of loading was controlled strain modified in that loading was halted at intervals to permit surface measurements to be made with a cathetometer equipped with a vernier scale to permit measurements to the nearest 0.005 cm.

After completion of the test the specimen was carefully cut in layers until the top of the first coil was exposed. A dial gage was then positioned above the gage as shown in Figure 11. Several readings were taken over the gage face and an average value was obtained. The specimen was further cut until the second coil was exposed. Again several dial gage readings were taken and the average was obtained. The difference of these two values less the thickness of the upper coil was used to get the clear coil spacing. These measurements are felt to be accurate to within 1 or 2 per cent. Table 2 is a tabulation of final coil position as measured mechanically and as determined from reference coil position for all tests.

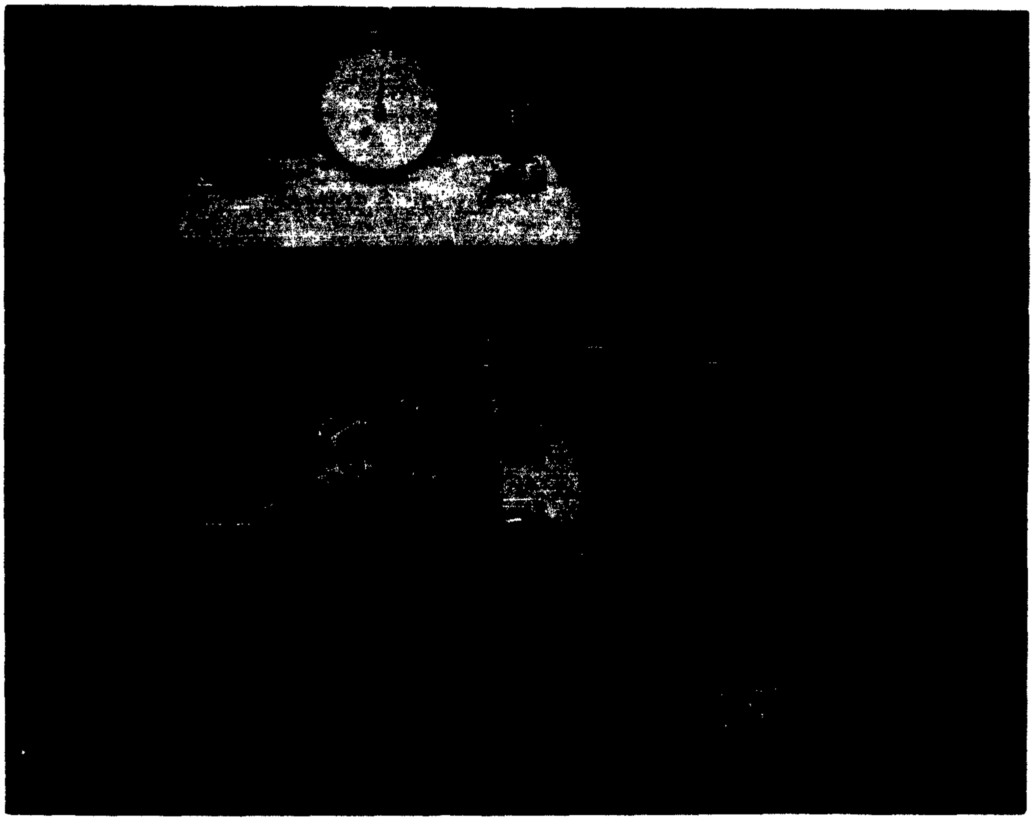


Fig. 14 DIAL GAGE APPARATUS FOR DETERMINATION OF FINAL COIL SPACING

TABLE 2

FINAL COIL SPACING

Test	Coil Spacing - (in.)		Per Cent Difference in Measurements
	Mechanically Measured, ± 2 Per Cent	Reference Coil	
1	0.353	0.3485	1.27
2	0.445	0.4574	3.02
3	0.365	0.3640	0.27
4	0.420	0.4257	1.36
5	0.391	0.3993	2.12
6	0.273	0.2703	0.99
7	0.409	0.4142	1.27
8	0.501	0.4950	1.22
9	0.493	0.4805	2.10
10	0.410	0.3927	4.20
11	0.311	0.3228	3.80

The per cent error was computed assuming the mechanically measured distance to be the correct spacing. This error includes the effects of both misalignment in placement and any additional misalignment resulting from lateral and shearing strains in deforming the specimen. As may be seen, the largest error is 4.2 per cent with the average being 2 per cent or less. These results definitely established the reliability of the physical measurements of the gages under static load applications.

Figures 15 to 21 compare gage computed strain to average strain. Figure 15 shows the ratio of the strain computed from gage output to the average strain for the larger gage embedded in the center of 4-in.-high specimens. It may be seen that this ratio is usually greater than unity. This is as might be expected since in the shorter specimen end effects would be relatively much greater. The adhesion of the specimen to the end plates tends to make the clay stiffer in those regions. Because of this, the strains at the center of the specimen would be expected to be greater than the average. Figure 16 is a similar plot for the smaller gage. Again it can be seen that the ratio is greater than unity. Very little difference in strain results from the difference in gage size. It is suprising that in some instances the gage strains are as much as 20 per cent greater than average at only 2 per cent average strain.

Figure 17 is a graphical solution for strain based on surface measurements for test no. 5 (see Table 2) with the smaller gage. On this basis it appears that the periphery strain is fairly uniform along the specimen length and compares well with average strain up to about 5 per cent strain. This is typical for those cases in which the gage was embedded in the center of the specimen. Above 5 per cent strain, the correlation is not as good, due to distortions on the surface resulting from the formation of failure planes.

Since the strain appeared to be uniform longitudinally along the specimen surface, it was decided to place the coils at the periphery. Figure 18 shows the ratio of gage computed strain to average strain for gages embedded at the periphery of the specimen. As can be seen, the ratio rapidly becomes less than unity for the small gage and is much less than unity for the larger gage embedded in a softer specimen. The strain, as computed from surface measurements, also becomes distorted (Figures 19 and 20). The curves tend definitely to flatten out in the region where the coils are located. It is believed that the effect of gage presence was more pronounced at the periphery due to boundary conditions since there was much less soil surrounding the gage forcing it to move together

Following these experiments, the gages were centrally embedded in 6-in long specimens and again loaded statically. It was anticipated that here end effects should be reduced resulting in a more uniform distribution of strain throughout the specimen Figure 21 shows the ratio of gage strain to average strain for both size gages. In these tests the stiffness of the soil, assuming the stiffness to vary inversely with the moisture content, was the dominant factor Both gages recorded greater than average strain in the stiffer soil and less than average strain in the softer soil condition This was probably due to a combination of two effects, i e., (1) the coil was very stiff in comparison to soil, hence, the stiffer the soil the less the stiffness mismatch, and the less the effect of gage presence, (2) at the higher moisture content the soil is above the sticky limit and adheres to foreign materials, thereby further complicating the soil-gage interaction problem.

Another factor which was considered was the location of failure within the specimen. If a failure plane occurs through the gage length (Figure 22a), it is quite understandable that gage strain could be greater than average strain only over the length ℓ_1 while the strain is computed from ℓ. However, the gage experiences slippage over its entire length Figure 22b depicts a possible failure intersecting the coil discs. It is probably that this type of failure occurred in test no 11 (Figure 21). While the actual location of the shear planes with respect to the coils could only be estimated on this test because the gage was centrally embedded, it did appear that the upper sliding wedge of the specimen was definitely above the coils. As is suggested in Figure 22b, this tends to force two soil wedges out and can cause extremely high stresses in the gage area, producing strains much greater than average Figure 22c shows a possible failure plane outside the gage area Average strain in this case would be increased by any slippage along the failure plane while the gage would be sensing only the compression of the specimen away from the failure zone. This could explain the results

Test	Symbol	Initial Coil Spacing (in.)	Initial Specimen Height (in.)	Water Content (%)
1	⊙	0.4516	4.04	38.1
2	⊛	0.5352	4.04	42.4
3	△	0.4523	3.96	45.0

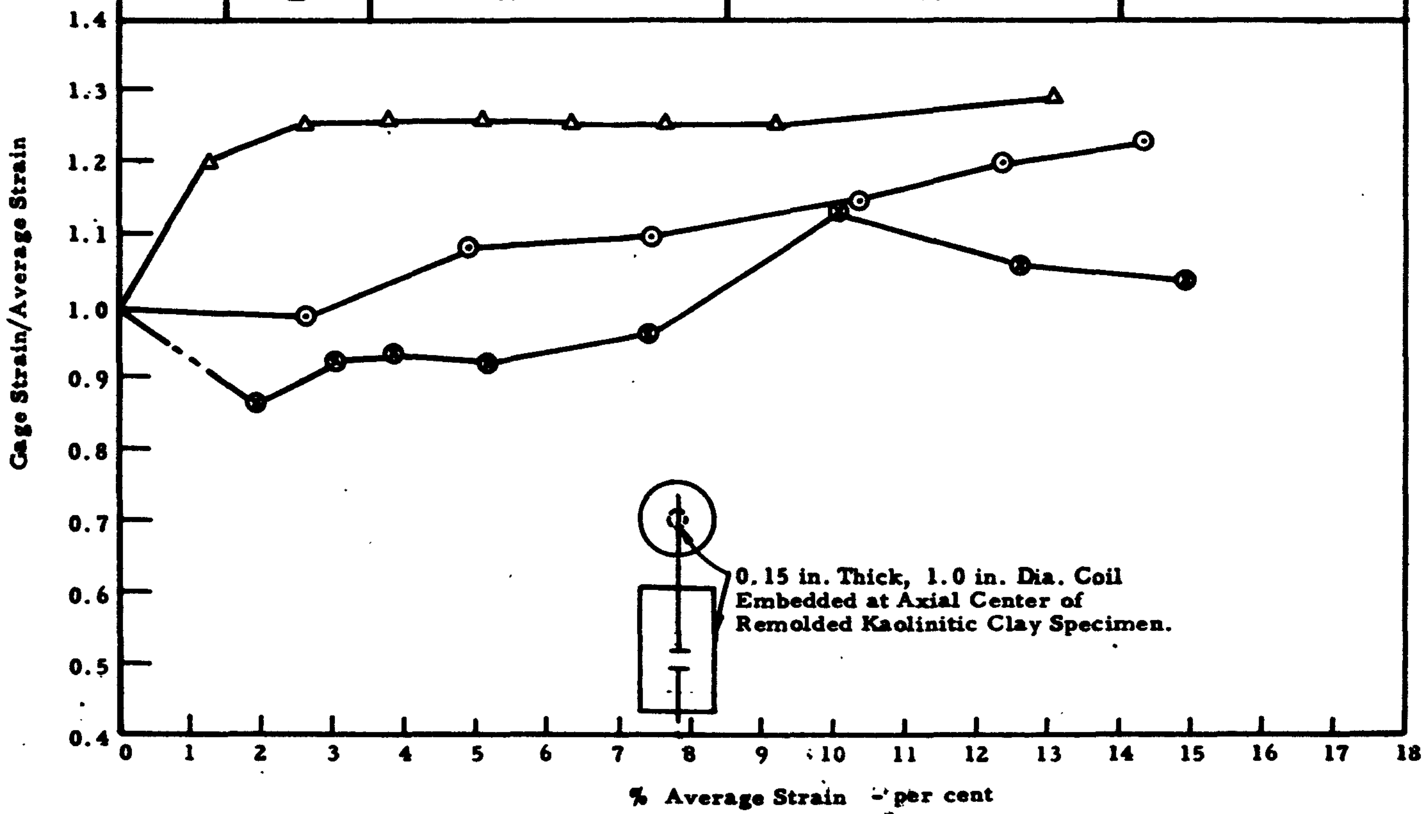


Fig. 15 COMPARISON OF GAGE STRAIN TO AVERAGE STRAIN, LARGER COIL CENTRALLY EMBEDDED IN THE CENTER OF 4-IN. LONG SPECIMEN

Test	Symbol	Initial Coil Spacing (in.)	Initial Specimen Height (in.)	Water Content (%)
4	⊙	0.4453	4.29	40.0
5	⊗	0.4450	4.01	44.6

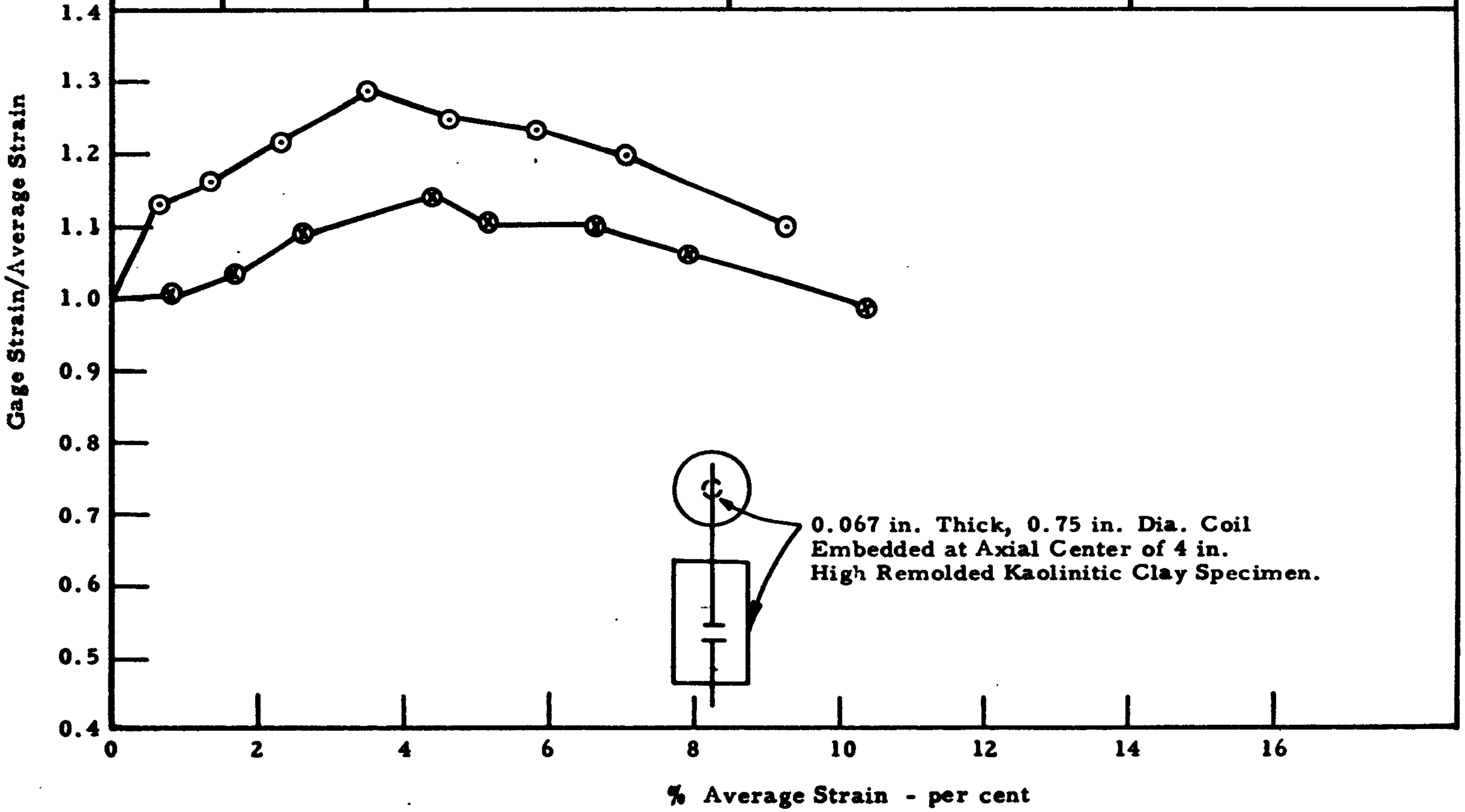


Fig. 16 COMPARISON OF GAGE STRAIN TO AVERAGE STRAIN, SMALLER COIL CENTRALLY EMBEDDED IN 4-IN. LONG SPECIMEN

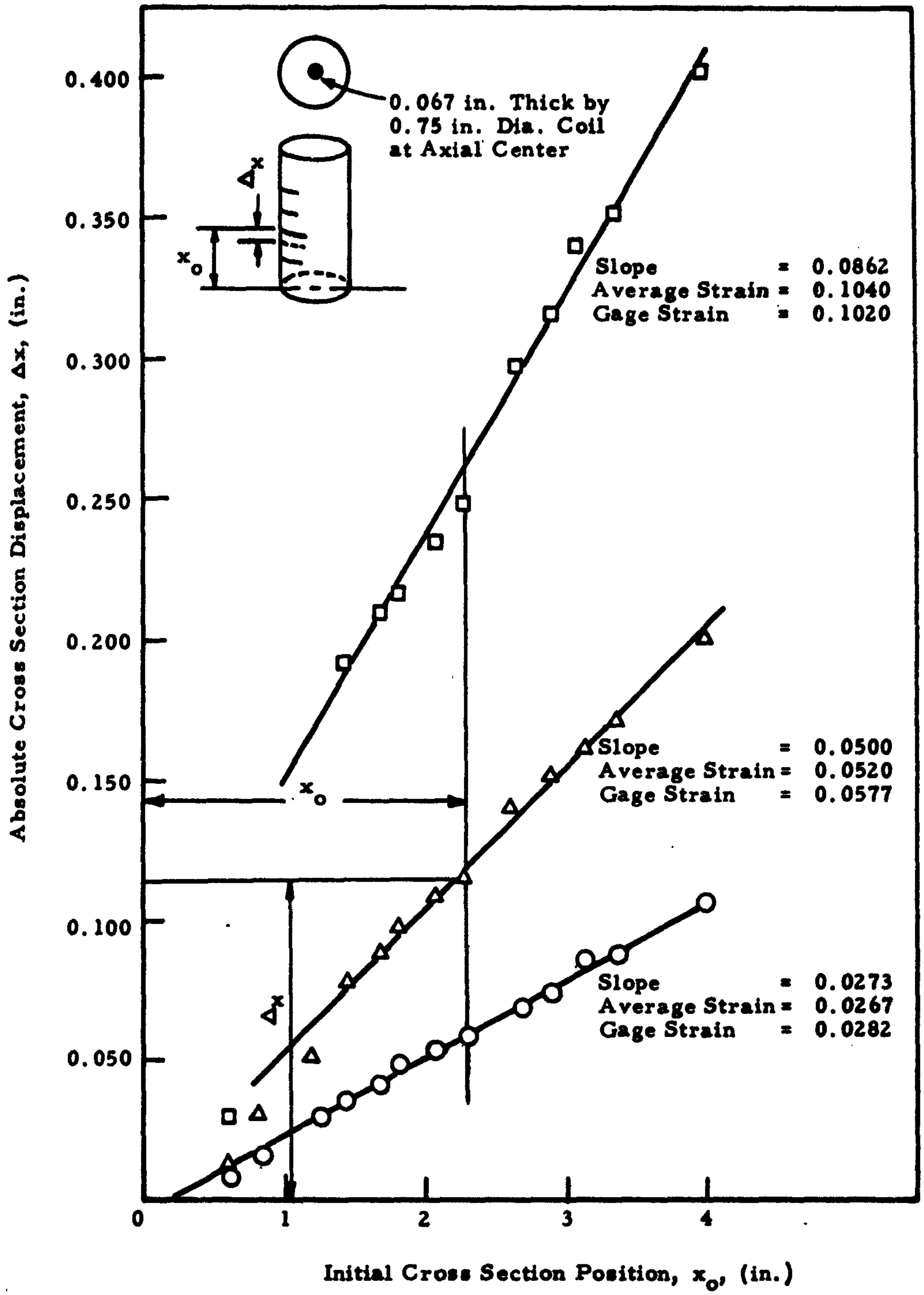


Fig. 17 STRAIN BY GRAPHICAL DIFFERENTIATION, SMALLER COIL CENTRALLY EMBEDDED IN 4-IN. LONG SPECIMEN

Test	Symbol	Initial Coil Spacing (in.)	Initial Specimen Height (in.)	Water Content (%)
6	⊙	0.3010	3.94	40.2
7	⊗	0.4322	3.89	46.4

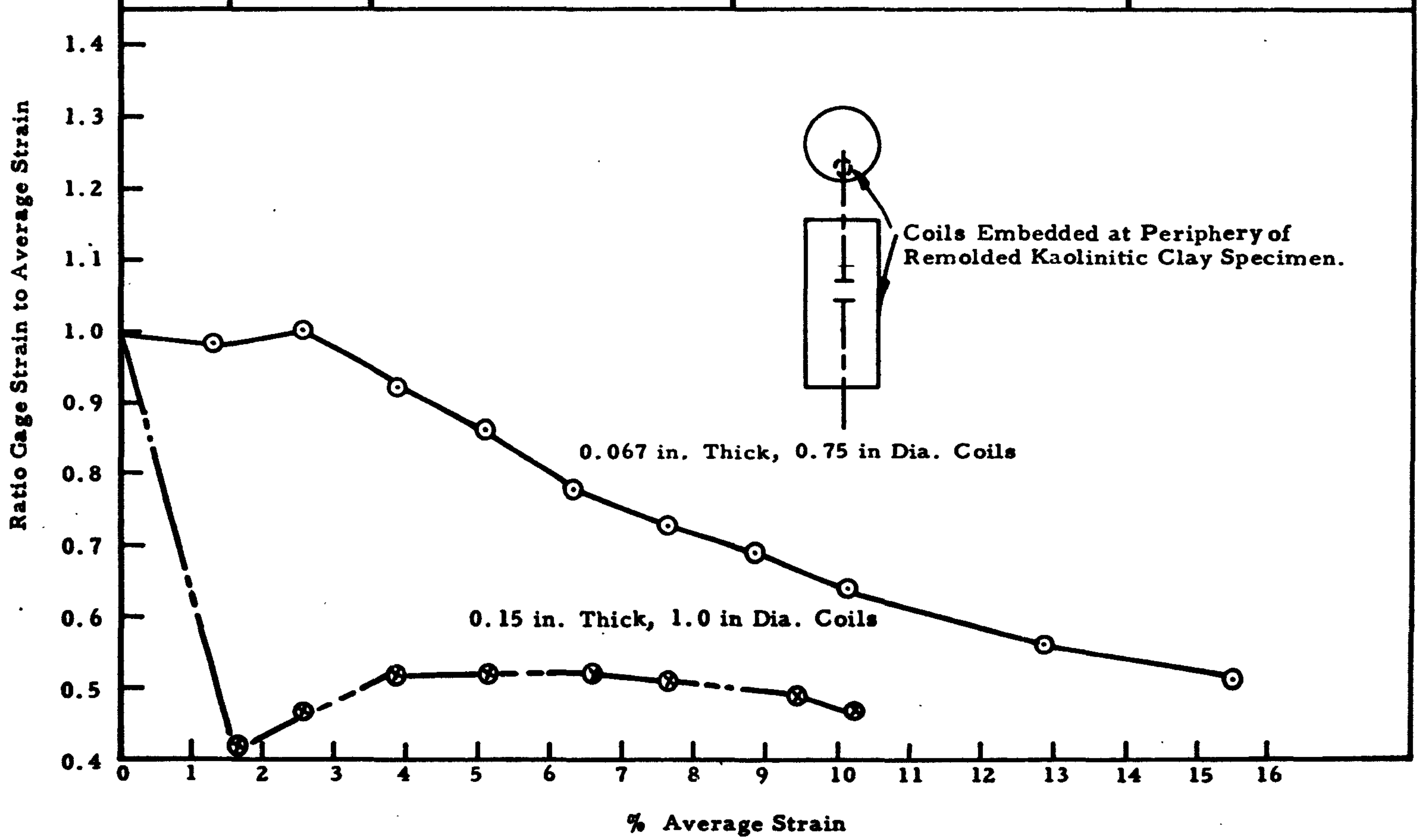


Fig. 18 PERFORMANCE OF BOTH SIZE COILS EMBEDDED AT PERIPHERY OF 4-IN. LONG SPECIMEN

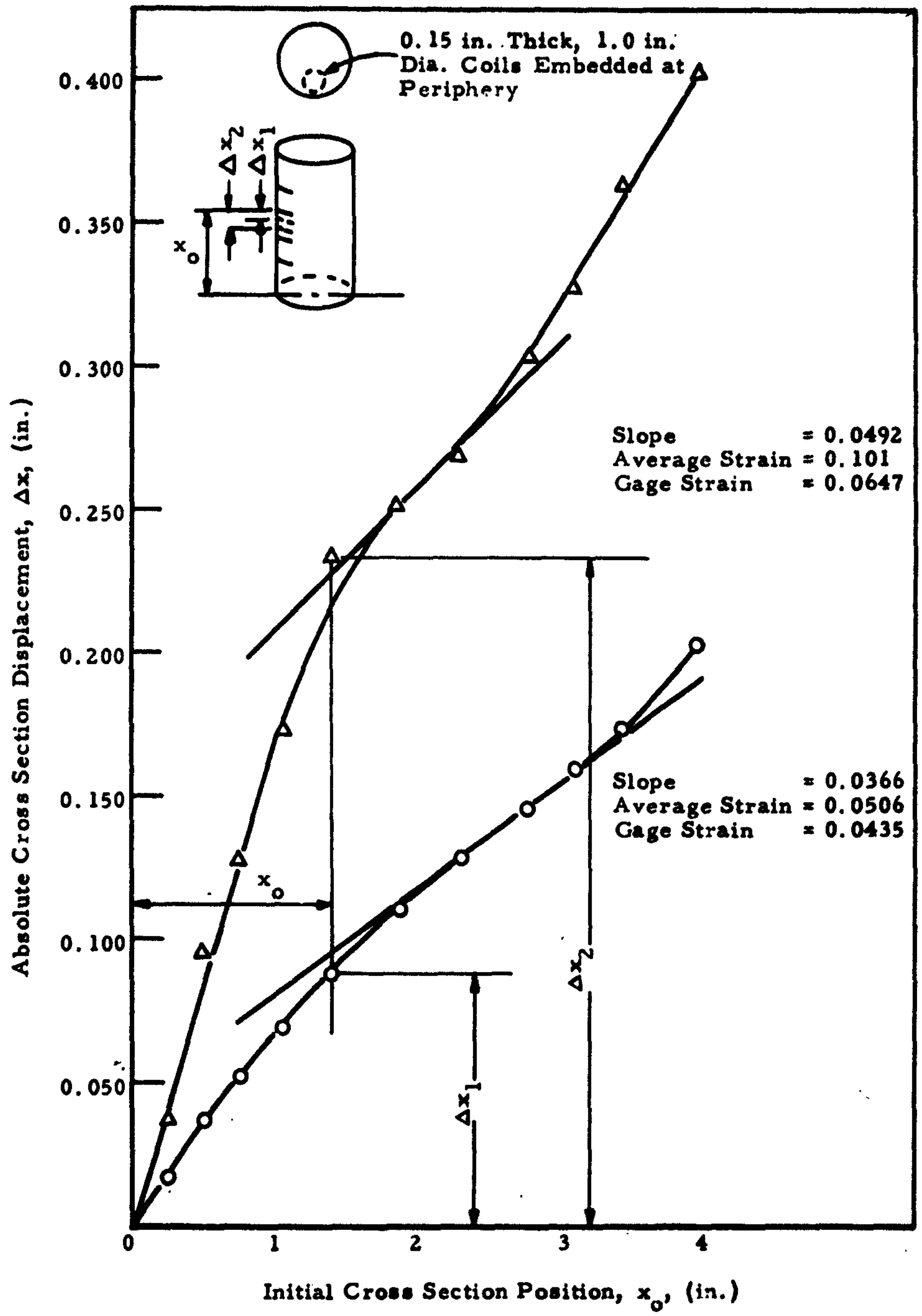


Fig. 19 STRAIN BY GRAPHICAL DIFFERENTIATION, LARGER COIL EMBEDDED AT PERIPHERY OF 4-IN. LONG SPECIMEN

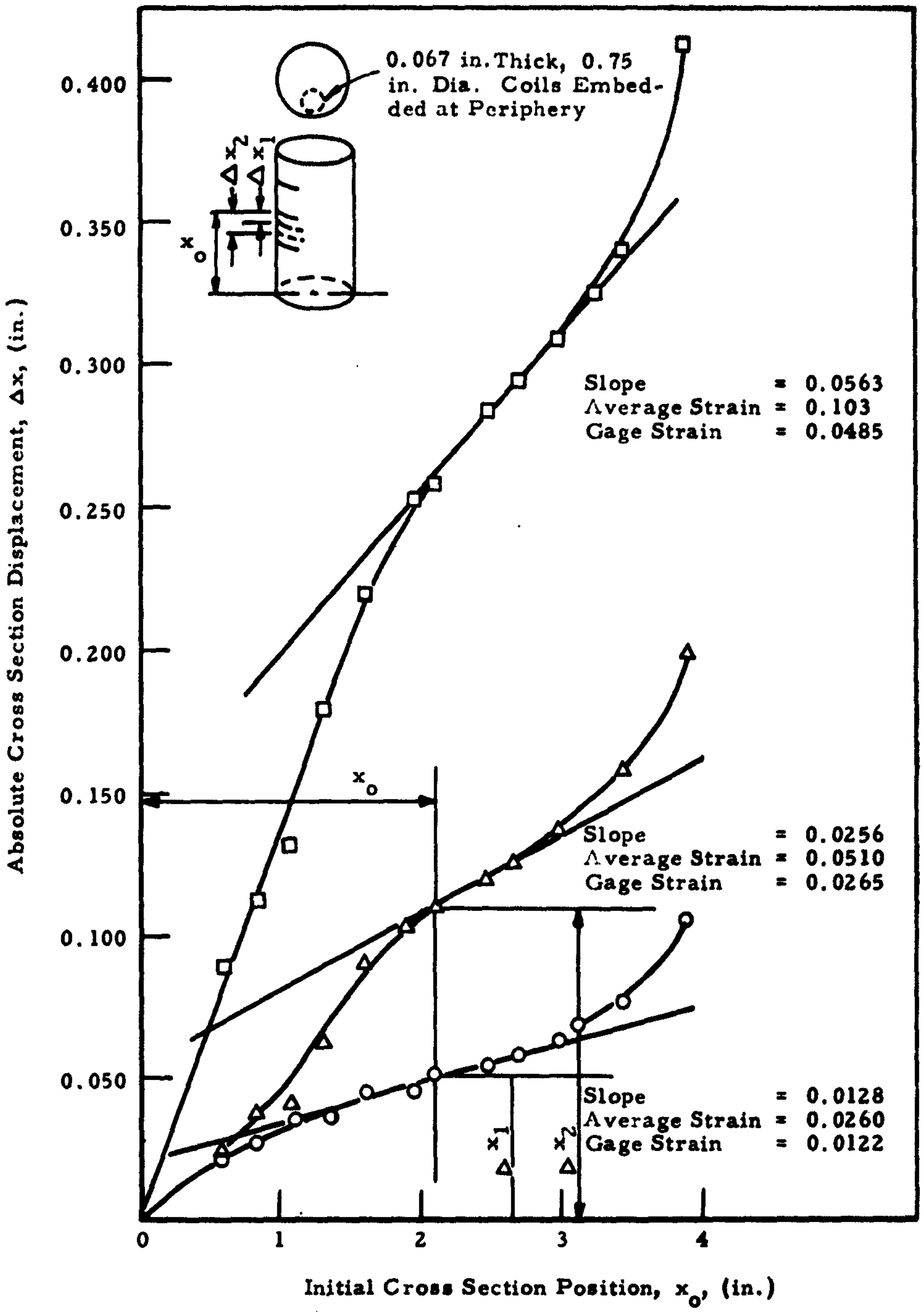


Fig. 20 STRAIN BY GRAPHICAL DIFFERENTIATION, SMALLER COIL EMBEDDED AT PERIPHERY OF 4-IN. HIGH SPECIMEN

Coil Size	Test	Symbol	Initial Coil Spacing (in.)	Initial Specimen Height (in.)	Water Content (%)
0.067 in. Thick by 0.75 in. Dia.	8	⊙	0.3228	6.25	38.4
	9	●	0.5101	5.75	49.37
0.15 in. Thick by 1.0 in. Dia.	10	△	0.4773	6.00	36.8
	11	□	0.4950	6.00	48.7

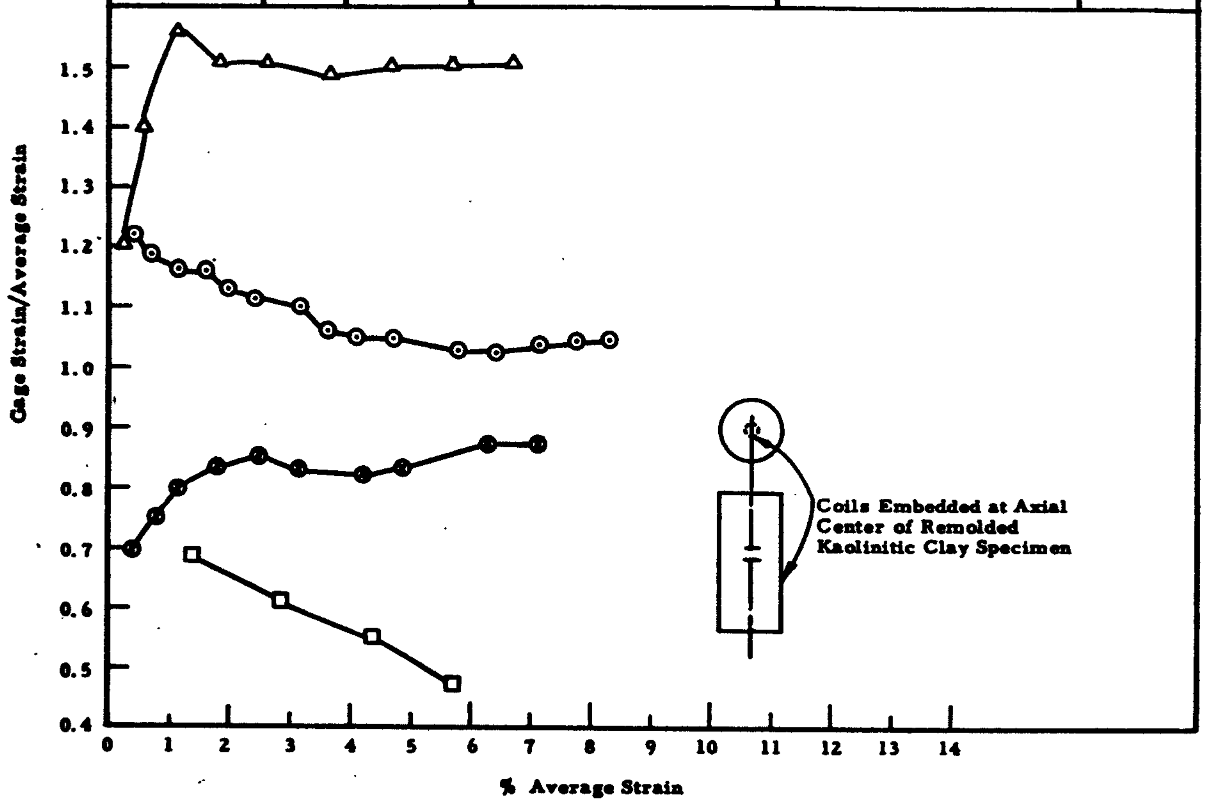


Fig. 21 COMPARISON OF GAGE STRAIN TO AVERAGE STRAIN FOR BOTH SIZE COILS CENTRALLY EMBEDDED IN 6-IN. LONG SPECIMEN

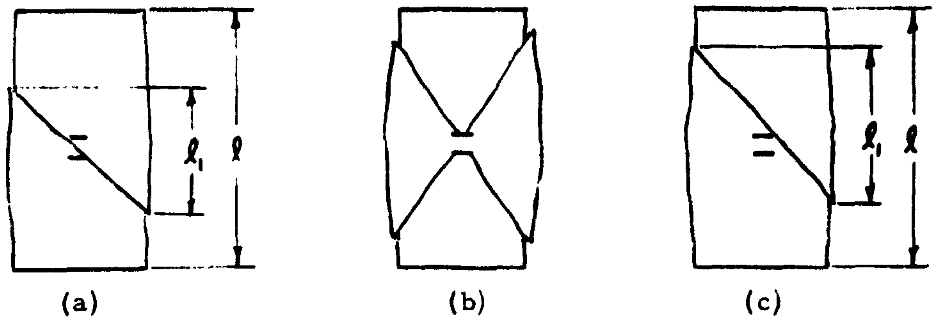


Fig 22 POSSIBLE LOCATIONS OF FAILURE PLANES:
(a) Through Gage Length, (b) Through Coil Discs,
(c) Outside Gage

of test no 2 (Figure 15), the only test in which gage strain was less than average strain for the gage centrally embedded in a 4-in. -high specimen

It is felt that location of failure planes may be significant even at less than 1 per cent strain. From Figure 14, it may be seen that the slope of the load-deformation curve begins changing at approximately 0.02 in deflection. In the specimen, this corresponds to 0.33 per cent strain. This change in slope could indicate the formation of failure planes and the beginning of effects discussed above at small percent strains.

In summary, it appears that the presence of the gage does distort the strain being measured to some extent With the coils placed at the specimen periphery, surface measurements are distorted. This shows up as increased soil stiffness in the vicinity of the gage It is believed the effect of the gage is more pronounced at the periphery where there is less soil surrounding the coils forcing movement together There is probably greater effect of gage presence in very soft clay than in stiff clay due to greater differences in the relative rigidity of the coils and soil and the increased adhesion between the softer soil and the coils. Conclusions relating to gage size cannot be drawn in that the nonuniformity of strain throughout the specimen is of far greater significance than the difference in gage sizes used.

Tests were next conducted to compare strain from gage output with average strain in sand specimens. These specimens were formed by pouring sand into a 2.8-in -diameter, 6 in -long mold with a rubber membrane lining. The sand was poured from a height of 18 in. to produce a medium-density (approximately 106 lb per cu ft, Figure 22) specimen. The gage was inserted as the specimen was prepared using the following procedure: Sand was poured to a predetermined level, near mid-height of the specimen. A coil was placed on the sand surface, positioned in the center of the mold by a 1/16 in diameter rod inserted through the center of the gage. Sand was then poured to a second predetermined level from 1/4 to 1/2 in. higher. The second coil was then slid down the rod and centered at this level. A slight amount of additional sand was then poured and the rod removed. Preparation of the specimen was then completed. A vacuum was applied to the base of the mold and the membrane liner sealed over a cap at the top of the specimen. The mold walls were then removed and the specimen was ready for testing

Tests were again conducted applying a controlled rate of strain. Figure 23 shows the ratio of gage strain to average strain for both size coils. Gage strain was less than average strain for all but one measurement. The nonuniformity of strain throughout the specimen and location of failure planes probably contributed significantly to scatter However, it appears that gage size effects in sand were more critical than in clay. This may have been due to frictional resistance between the sand particles and the coil discs, a condition similar to that which occurred in clays with high moisture content. In fact, the results were very similar

4 3 Dynamic Evaluation of Gage Performance in Soil

Evaluation of the gage under dynamically applied loads has to date, been confined to verification of gage output. For this investigation, the coils were embedded at the periphery of a remolded clay specimen. The procedure of specimen preparation and gage insertion was identical to that followed for the static tests. After removal of the specimen from the mold it was trimmed rapidly to expose the edge of the coils. A Fastax camera was then positioned to record coil movement during transit of an applied shock load caused by dropping a weight on the specimen.

Coil Size	Test	Symbol	Initial Coil Spacing (in.)	Vacuum Confining Pressure in. of Hg	Density #/ft^3
0.067 in. Thick by 1.0 in. Dia.	1	○	0.4562	25	106.8
	2	○	0.3775	15	105.7
0.15 in. Thick by 1.0 in. Dia.	3	△	0.3352	25	105.9
	4	□	0.3096	15	106.2

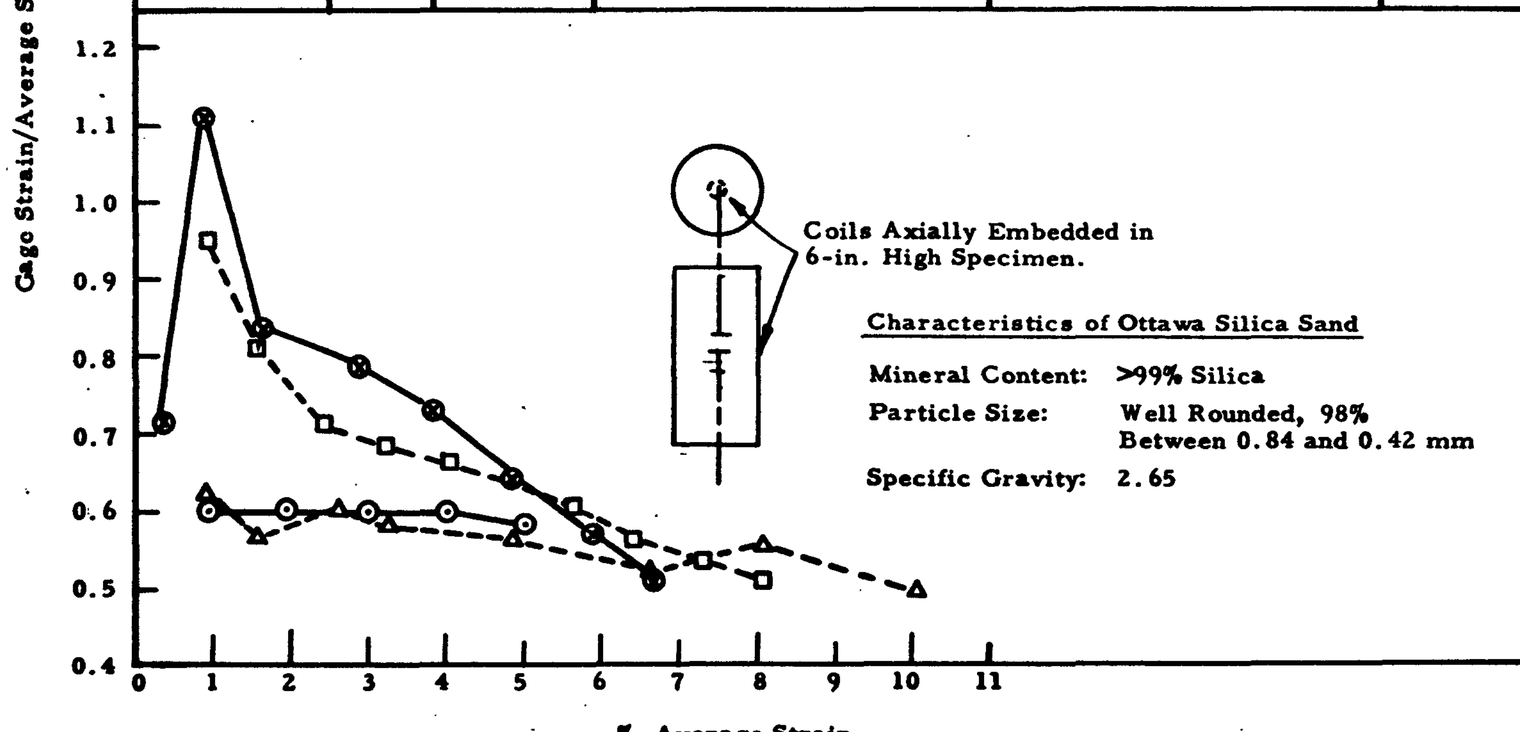


Fig. 23 COMPARISON OF GAGE STRAIN WITH AVERAGE STRAIN, BOTH SIZE COILS CENTRALLY EMBEDDED IN 6-IN. LONG SAND SPECIMEN

Gage sensitivity and calibration varied with coil separation or spacing. Because of this, calibration was required after the coils were embedded in the test specimen and this separation determined. Calibration was, however, a short and simple procedure which was accomplished immediately prior to testing, thereby eliminating possible errors which might have introduced changes with time and temperature. The procedure was that given in section 3.3.

Load was applied by means of a falling weight. The specimen was positioned beneath a 3 in. diameter tube through which a 5-lb weight was dropped from a height of 8 in. Gage output was recorded on an oscilloscope which was triggered as the weight left the tube.

A plot of gage spacing versus time was then obtained from both the oscilloscope record and from the high speed motion pictures Figure 2 is an enlargement of the oscilloscope record with plotted check points obtained from the film As can be seen, the correlation is quite good. The scatter is of the order of magnitude of the accuracy with which the film can be analyzed

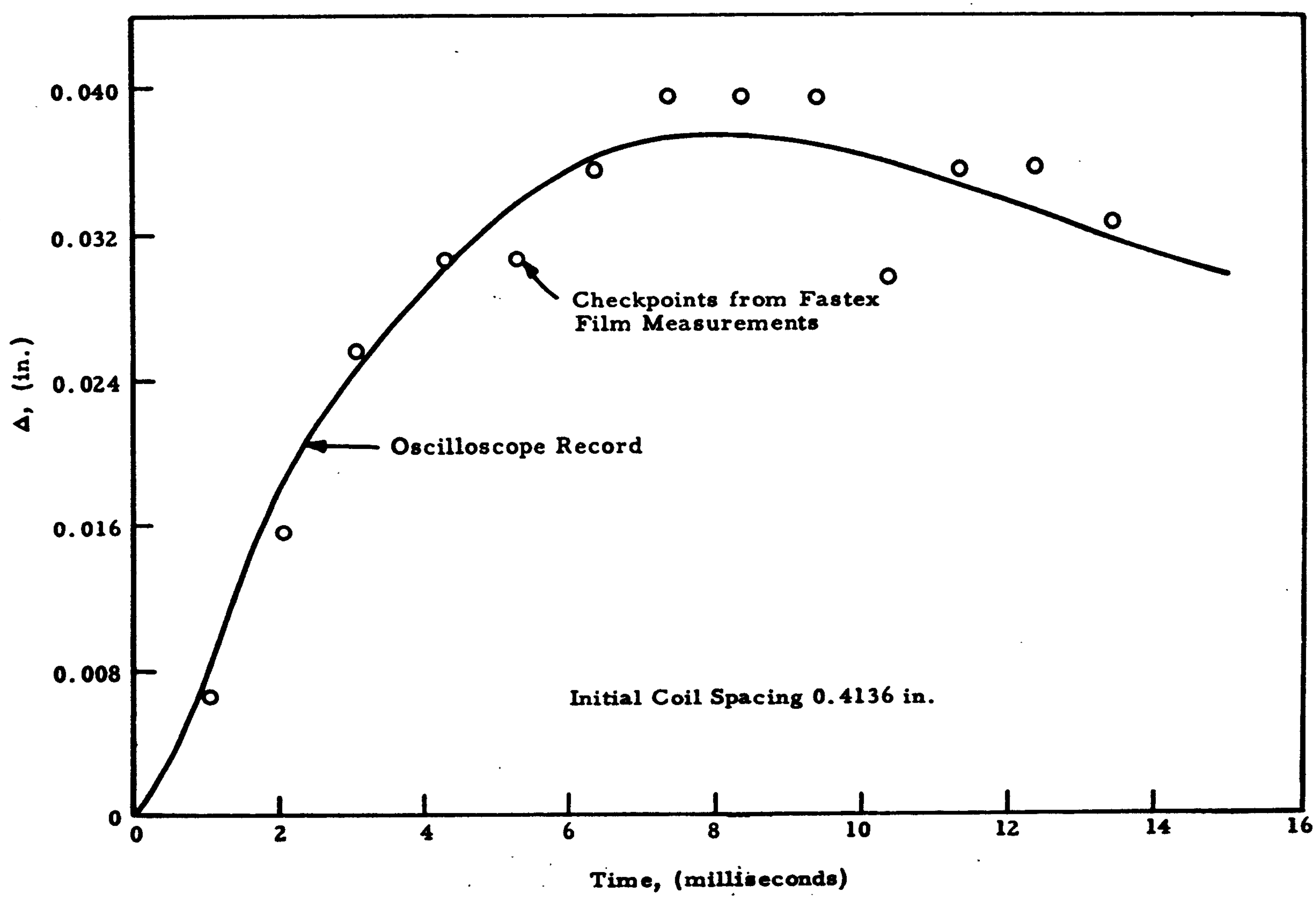


Fig. 24 COMPARISON OF COIL SPACING AS DETERMINED FROM OSCILLOSCOPE RECORD WITH HIGH SPEED MOTION PICTURE MEASUREMENTS

5. CONCLUSION

A gage operating on the principle of an air-core differential transformer and a null-balance system appears to offer a satisfactory method of measuring strains in soil. With proper electronic amplification and recording circuitry, the gage is extremely sensitive to small axial differential movements, yet is relatively insensitive to the effect of lateral and rotational displacements such as might be produced by lateral and shearing strains.

The instrument is adaptable to a wide variety of soil-strain measurement applications and has many additional desirable features.

(1) There is no physical transducer between the driver and sensor coil in the soil sample. As such, the soil may be placed more uniformly within the gage length and actuation of the gage offers no resistance to the movement of the soil. This is a significant improvement over a mechanically coupled gage which not only complicates uniform placement of the soil but also requires that protection be given to the moving linkage to prevent binding by interference of soil particles.

(2) The instrument has a wide frequency response thereby making possible the measurement of transient strains with rise times of less than 75 microseconds.

(3) Precise spacing of the two coils as they are being inserted in the soil is not required.

(4) In static tests, accuracy of better than one per cent of initial spacing can be attained Calibration for dynamic tests can be made quickly, simply, and precisely, providing accuracy on the order of two per cent of initial spacing

(5) The sensor and driving coils can be made in different sizes to most readily adapt to the specific application.

Tests have shown that the gages can be consistently placed within the design tolerances to produce a high degree of accuracy in measurement. The method of placement used in the tests has the disadvantage that withdrawal of the rod used to align coil position while the specimen was being formed leaves a small hole, but this is not believed to be significant. For specimens constructed with only a slight amount of agitation, such as a poured-sand specimen, the coils may be placed quite satisfactorily in small specimens by eye, while in large specimens a plumb bob would allow sufficiently accurate placement. However, for samples which require a heavy agitation, such as a procter hammer for compaction of clay, some means must be used to stabilize the coil positions until the compaction of the soil in the vicinity of the gage is completed.

The gage suffers the drawback of all gages, in that by its very presence in the soil, it influences somewhat the phenomenon which it is meant to measure. Tests results have given an indication of the distortional effects of this gage on the strain field in its vicinity but additional investigation is required to fully evaluate gage performance This effect does appear to be of significant magnitude when embedded in sand. When embedded in clay, the effect of gage presence appears to be much less pronounced and, in fact, may be negligible in stiff soils. Detailed conclusions as to gage effects in either medium cannot be made without further detailed study It would appear desirable, however, to reduce the coil-size spacing ratio. This may be accomplished by further refinement in electronic instrumentation to permit fewer number of coil windings and by winding the coils with finer wire.

6. RECOMMENDED FUTURE WORK

To evaluate the significance of the effect of gage presence and to reduce this effect by refinement and modification of the gage, it is recommended that the following studies be undertaken:

6.1 Soil Mechanics Studies

(1) Make up a number of identical coils and put them in various size molds to obtain a range of over-all gage sizes.

(2) Prepare large soil specimens, perhaps 6 in. in diameter, inserting a number of gages at various positions radially from the center at the same cross-section near the top, center, and bottom of the specimen. Strain would then be obtained from (a) the output of each gage, (b) total deformation of the specimen, and (c) a surface measuring technique. Careful analysis could be made as to location of failure planes. Results could then be analyzed to determine trends relating to gage size-spacing ratios.

(3) Prepare smaller specimens, 3 in. and 1 in. in diameter in as reproducible a manner as possible. Test these without gages and with gages of varying sizes. Both load and strain could be recorded and analyzed to determine if any effect in over-all load-strain characteristics of the specimen can be related to gage size.

(4) Prepare specimens in a slurry and consolidate with gages in place. The soil should be quite uniform throughout these specimens, including that in the vicinity of the gages. Thus, the influence of specimen nonuniformity due to preparation and gage insertion should be reduced to a minimum. Tests would be conducted as in (1) and (2) above. Results again would be analyzed to determine trends related to gage size. Comparison of any trends established here would be made with those established in (1) and (2) above to determine if the method of placement causes any significant changes in strain.

6.2 Electronic Studies*

Alternate Coil Design

(1) Modify present arrangement of coil pairs to replace pick-up coils by a thin flat metal plate The two driver coils in this case would be balanced in an inductance bridge circuit As the coil and metal plate move together the coil inductance changes, thereby producing a proportional unbalance in the inductance bridge circuit. Preliminary investigation of this principle has been made and sensitivity appears to be of a satisfactory magnitude. Modification of the present electronic amplifying equipment will be necessary to make a more detailed examination. If this principle proves satisfactory, investigation could be conducted as to the feasibility of using structural models as the replacement for the pick-up coil Thus, an extremely useful tool for the study of the soil-structure interaction problem may be developed.

(2) Investigate feasibility of applying the principle of operation of the present gages to develop a gage for field use. This would necessarily mean using larger coils and more refined instrumentation It is recommended that a preliminary investigation be made to determine the size coils which would be required

Improvement of Coil Design and Electronic Auxiliaries

(1) Study just how small the gages could be made and still retain enough sensitivity so that small changes in coil separation can be detected within acceptable tolerances Coil sensitivity in the normal direction is related to the number of turns of the coil and the sensitivity of the electronic equipment. It is obvious that fewer turns reduces the size of the coil. However, this also causes a loss in coil sensitivity From the concept of soil-gage interaction, it is advisable to make the gages as small as possible. However, there exists some minimum size under which the low sensitivity becomes prohibitive, regardless of the degree of refinement attained in instrumentation.

(2) Undesirable coil sensitivity to transverse and rotational movement seems to be related to the ID of the driver coil and the OD of the sensor coil. Present data on this effect are limited but it seems reasonable that there exists some OD sensor-ID driver ratio that will give the lowest sensitivity to these movements and not distort the uniform magnetic field. By finding the most adequate ratio to give the lowest sensitivity, the possible movement of one coil in relation to the other in these directions becomes maximized.

APPENDIX I

ELECTRONIC AUXILIARY COMPONENTS

TABLE I-1

COMPONENT PARTS LISTING

Component		Manufacturer	Stocknumber or Manufacturers Identification Number
Power Supply		Dressen-Barnes Electronics Corp.	Model 20-30
Oscillator		Delta-F	P.S. Model 20-30
Pot-Core T1 & T2 Cup Core (4)		General Ceramics	Type F671-H CF 214
Resistors	R1, R9	Standard items available any electronic supply house.	4.7K
	R2		33K
	R3, R10		47Ω
	R4		330Ω 2W
	R5, R6		100Ω
	R7, R8		47K
	R11		1K
	R12		22K
	R13		82K
	R15		1K 1W
	R16		1K
	R17, R19, R20, R26		10K
	R18		20K
Capacitors	C1	Standard items available any electronic supply house.	.25MF
	C2, C5, C7		10MF
	C3, C4		0.05MF
	C6		0.01MF
	C8, C9		0.02MF
	C10		0.003MF
Transistors	Q1, Q3	Texas Instrument	2N 696
	Q2		2N 338

TABLE I-1(Cont.)

Component	Manufacturer	Stocknumber or Manufacturers Identification Number
Silicon Diodes D1, D2, D3, D4	Sylvania	IN 914
LP Filter	United Transformer Corporation	UTC LP Filter LMI 10,000
Panel Meter	Simpson	Model 1329 (100-0-100 Micro-ammeter)
Transistor Holder and Heat Sink (2)	IERC-Magnuson Associates	IERC TXB-032-037B
Steatite Ceramic Insulation Switch	Oak	57F637
Plug	Amphenol	Amphenol M58106 A145-5P

COILS The driver coils (300 turns) and the sensor coils (150 turns) were manufactured for the Armour Research Foundation by the Rockville Indiana plant of DORMEYER INDUSTRIES These coils are identified as Part Numbers 3701 and 3702 on a Dormeyer quotation dated 15 January 1963, in response to an Armour Research Foundation Purchase Order No 53560.

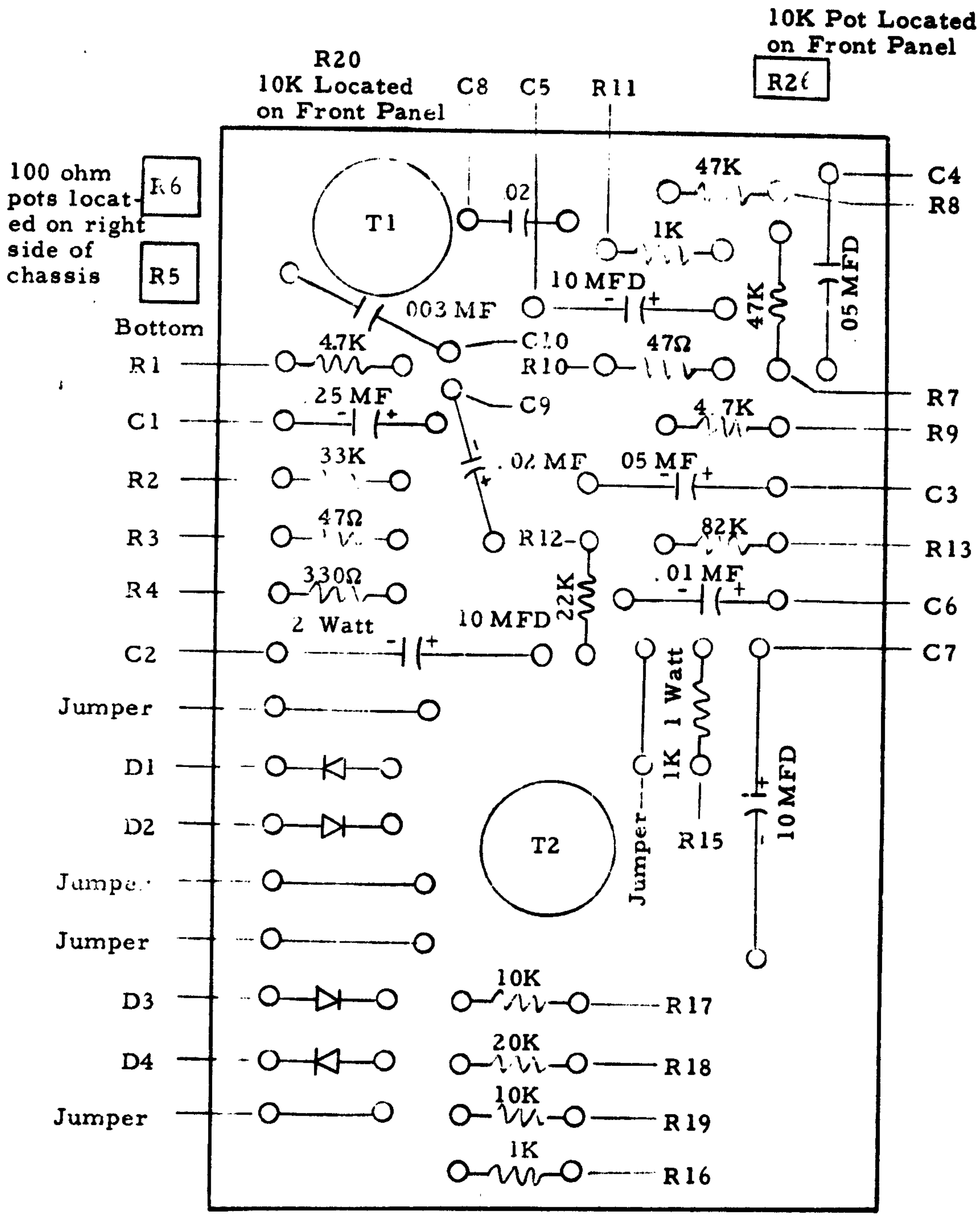


Fig. I-1 ELECTRONIC CIRCUIT COMPONENT LOCATION

TABLE 1-2

20-30 **DRESSEN-BARNES ELECTRONICS CORPORATION** 20-30

INSERT A. PARTS LIST AND SCHEMATIC

(To be inserted in 20 Series Instruction Manual)

20 SERIES DC POWER SUPPLY
MODEL 20-30

A-1. PROCEDURE FOR ORDERING REPLACEABLE PARTS

When ordering parts from the factory always include the following information:

1. Power supply model number
2. Power supply serial number
3. Dresden-Barnes part number
4. Description of part

A-2. REPLACEMENT PARTS LIST

Item	Schematic Symbol	Description	D/B Part No.
1	C1, C2	Capacitor, Fixed, Electrolytic 350 MFD, +50%, -10%, 70 volts	513310-2
2	C3	Capacitor, Fixed, Electrolytic 5 MFD, +100%, -10%, 50 volts	336001-4
3	C4	Capacitor, Fixed, Electrolytic 150 MFD, +100%, -10%, 50 volts	513309-2
4	C5	Capacitor, Fixed, Electrolytic 20 MFD, +100%, -10%, 50 volts	336001-3
5	C6	Capacitor, Fixed, Electrolytic 20 MFD, +100%, -10%, 50 volts	336001-3
6	C7	Capacitor, Fixed, Ceramic Disc 0.01 MFD, ±20%, 50 volts	332502-1
7	CR1	Rectifier, Silicon Type DI-52, Diodes Inc.	432601-63
8	CR2-CR5	Rectifier, Silicon Type DI-52, Diodes Inc.	432601-63
9	F1	Fuse, Medium Blo Type 3AG, 0.5 Ampere	377401-26
10	Q1	Transistor, Germanium 2N378, Tungsol	478801-12
11	Q2	Transistor, Germanium 2N378, Tungsol	478801-12
12	Q3	Transistor, Germanium 2N226, Philco	478801-9
13	Q4, Q5	Transistor, Germanium (matched pair), 2N227, Philco	478801-19
14	R1	Resistor, Adjustable, Wire Wound 7.5 ohms, ±10%, 10 watts	438010-104
15	R2	Resistor, Fixed, Composition 3,300 ohms, ±10%, 1 watt	MS35044-16K
16	R3	Resistor, Fixed, Composition 5,100 ohms, ±5%, 1 watt	MS35044-118J
17	R4	Resistor, Fixed, Composition Calibration, 1 watt	
18	R5	Resistor, Fixed, Composition 100 ohms, ±10%, 0.5 watt	MS35044-7K
19	R6	Resistor, Fixed, Composition 12K ohms, ±10%, 0.5 watt	MS35043-210K
20	R7	Resistor, Fixed, Wire Wound 500 ohms, ±5%, 3 watts	438075-27
21	R8	Resistor, Fixed, Composition Calibration, 0.5 watt	
22	R9	Resistor, Variable, Wire Wound 500 ohms, ±30%, 5 watts	427501-22-4
23	R10	Resistor, Fixed, Wire Wound 2,500 ohms, ±5%, 3 watts	438075-92
24	R11	Resistor, Fixed, Composition Calibration, 0.5 watt	
25	R12	Resistor, Fixed, Composition 1,000 ohms, ±10%, 0.5 watt	MS35043-13K
26	R13	Resistor, Fixed, Composition 1,000 ohms, ±10%, 0.5 watt	MS35043-13K
27	R14	Resistor, Fixed, Composition Calibration, 0.5 watt	
28	R15	Resistor, Fixed, Composition 3,900 ohms, ±10%, 0.5 watt	MS35043-207K
29	R17	Resistor, Fixed, Composition 1,000 ohms, ±10%, 0.5 watt	MS35043-13K
30	T1	Transformer Power	513168-6
31	Z1	Zener Diode 1N749, Pacific Semiconductor	490001-1
32	Z2	Zener Diode 1N752A, Pacific Semiconductor	490001-5
33		Schematic	513288-F

DRESSEN-BARNES ELECTRONICS CORPORATION

I SPECIFICATIONS FOR STANDARD UNITS (For modifications, see table)

INPUT: 105 to 125 volts AC, single phase 60 to 400 cycles per second.

REGULATION: For a line change from 105 to 125 volts AC the maximum output voltage change is 10 millivolts.
For a load change from zero to maximum rated current, the maximum output voltage change is 10 millivolts.

RIPPLE: The maximum ripple is 1 millivolt RMS under all conditions within rated operating range.

OUTPUT IMPEDANCE: 500 kilocycles 1.5 ohms. Impedance may be reduced as desired by adding capacitance externally across the output.

TRANSIENTS: No turn-on or turn-off transients. No transients due to line voltage change. The maximum load transient recovery time is 100 microseconds.

OVERLOAD PROTECTION: This series of DC power supplies is protected against overload by a DC fuse.

CONTROLS: A voltage control accessible from the top of the case varies the output voltage over the range specified for each individual model (See OUTPUT).

TERMINATIONS: Solder terminals are the standard input and output terminations for this series of DC power supplies.

MAXIMUM OPERATING AMBIENT: 50 degrees centigrade

OVERALL SIZE: 2-7/8 inches wide, 5-1/4 inches high, 4 inches deep.

WEIGHT: Net: 3 pounds; Shipping: 4 pounds.

OUTPUT:

Model	Nom. Volt.	Volt. Adj. (%)	Current (MA)	Model	Nom. Volt.	Volt. Adj. (%)	Current (MA)	Model	Nom. Volt.	Volt. Adj. (%)	Current (MA)
20-2	2	±10	750	20-13	13	±5	500	20-32	32	±5	300
20-3	3	±10	750	20-14	14	±5	500	20-36	36	±5	275
20-4	4	±10	750	20-15	15	±5	475	20-40	40	±5	250
20-5	5	±5	750	20-16	16	±5	475	20-45	45	±5	225
20-6	6	±5	750	20-18	18	±5	450	20-50	50	±5	225
20-7	7	±5	650	20-20	20	±5	425	20-55	55	±5	200
20-8	8	±5	600	20-22	22	±5	400	20-60	60	±5	175
20-9	9	±5	550	20-24	24	±5	375	20-75	75	±5	125
20-10	10	±5	550	20-26	26	±5	350	20-80	80	±5	125
20-11	11	±5	550	20-28	28	±5	350	20-90	90	±5	100
20-12	12	±5	550	20-30	30	±5	325	20-100	100	±5	100

MODIFICATIONS: If your 20-Series Power Supply model number has an "M" suffix, it is a modified unit. The following table defines various standard modifications:

Modification Code (Suffix to Model No)	Description or Modification	Modification Code (Suffix to Model No)	Description or Modification
M1	Octal Plug (instead of solder terminals)	M80	M1 and MT80
		M82	M1, MT80 and MT2
M2	M1 and MT2	M83	M1, MT80 and MT3
M3	M1 and MT3	M84	M1, MT80 and MT4
M4	M1 and MT4	M85	M1, MT80, MT2 and MT3
M5	M1, MT2 and MT3	M86	M1, MT80, MT2 and MT4
M6	M1, MT2 and MT4	M87	M1, MT80, MT3 and MT4
M7	M1, MT3 and MT4	MT80	±10% adjust (instead of ±5%)
MT2	Remote Sensing	MT82	MT80 and MT2
MT3	Remote Voltage Adjust	MT83	MT80 and MT3
MT4	Remote Fuse	MT84	MT80 and MT4
MT5	MT2 and MT3	MT85	MT80, MT2 and MT3
MT6	MT2 and MT4	MT86	MT80, MT2 and MT4
MT7	MT3 and MT4	MT87	MT80, MT3 and MT4

DRESSEN-BARNES ELECTRONICS CORPORATION

II GENERAL DESCRIPTION

The Dressen-Barnes 20 Series DC Power Supplies produce a regulated DC voltage adjustable to ±5% and ±10% of nominal voltage at output currents from zero to maximum rated current (see Specifications, page 3, for individual model numbers and outputs). The supplies are regulated against changes in line and/or load conditions. The information in this manual is general and covers all 20 Series Power Supplies. Refer to Insert "A" for a circuit diagram and replacement parts list of your power supply.

2-1. FLOATING OUTPUT

The plus (+) and minus (-) output terminals are insulated from chassis ground. Either output terminal may be grounded. Several supplies may be connected in series for higher voltage by contacting the factory for instructions. Parallel operation of the supplies is not recommended.

III INSPECTION

When a 20 Series Model Power Supply is received, inspect it for any damage it may have received in shipment.

Operate the power supply to make certain that it is functioning satisfactorily (see Paragraph 6-2, CHECK-OUT PROCEDURE).

IV OPERATING INSTRUCTIONS

4-1. INPUT AND OUTPUT CONNECTIONS

The input and output terminal designations are shown adjacent to their respective terminals. See Figure 1 and Insert A schematic

4-2. VOLTAGE CONTROL

The voltage control will increase the output voltage when rotated in a clockwise direction. Adjust the voltage control to the desired voltage as indicated by an externally connected meter. (See Fig I-2)

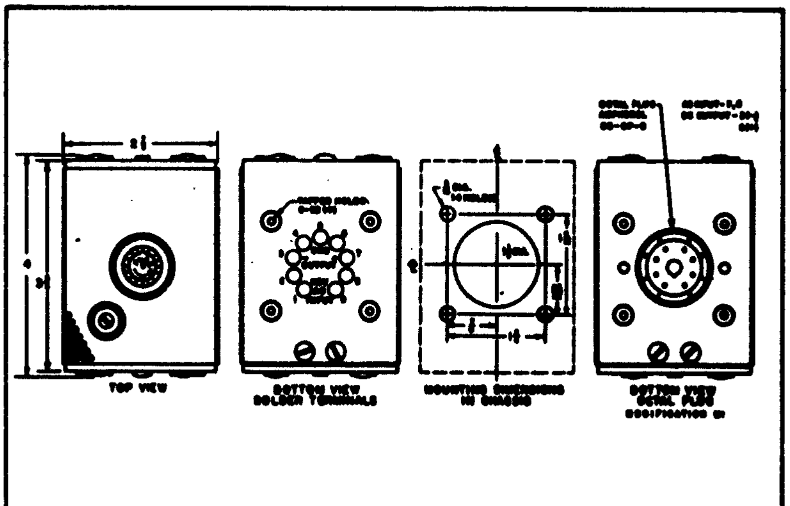


Fig 1-2 Top and Bottom View and Mounting Dimensions of Power Supply

V CIRCUIT DESCRIPTION (See Fig.) Based on circuitry typical of 20 Series modules

The input voltage is applied directly to transformer T1.

The AC output of T1 is divided into two secondary windings and rectified by diodes CR1 and CR2-CR5.

The DC output from diode CR1 is smoothed by an R-C filter (capacitors C5 and C6 and resistor R12) and used for bias supply voltage.

The DC output from CR2-CR5 is smoothed by capacitors C1-C2. A short circuit limiting resistor (R1) absorbs most of the voltage ahead of transistor Q1 under a short circuit surge. This limits the wattage across Q1 to a value below its maximum dissipation specification.

The DC voltages across capacitors C1-C2 and C5-C6 will change with changes in output load current and/or input voltage conditions. The voltage across capacitors C1-C2 is always higher than the output voltage of the power supply.

To regulate the output voltage, a series regulator is connected between fuse F1 and the negative (-) output terminal. This regulator consists of a power transistor, Q1. This transistor is so controlled that it will always absorb the difference between the unregulated voltage at F1 and regulated output voltage of the power supply.

A steady reference voltage of approximately 5 volts is provided by the Zener diode Z2. This reference voltage is connected to the base of transistor Q4, through resistor R5. Resistors R5 and R14 compensate for line changes by allowing a small compensating current to flow through Z2.

Resistors R7 to R11 form a voltage divider string, biasing the base of transistor Q5 approximately equal to the base of Q4. If the voltage across one of the resistors is held constant, the ouput voltage is constant. The string resistor, R9 controls the output voltage swing.

If the voltage across resistors R7-R11 should change, the bias on the bases of the difference amplifier, Q4-Q5 would no longer be equal. This change is amplified at the collector of Q4 which drives Q3. The output from Q3 is amplified by Q2. The output of Q2 controls the series regulator Q1. A few millivolts change across R7-R11 will completely control the voltage across the series regulator. The change in voltage across the series regulator is always the amount required to prevent further change in voltage across R7-R11 and therefore change in output voltage.

A fuse, F1, located between R1 and Q1, protects the circuit components from overload. If an overload occurs, the fuse blows cutting off the voltage to the series regulator and the output current drops to zero.

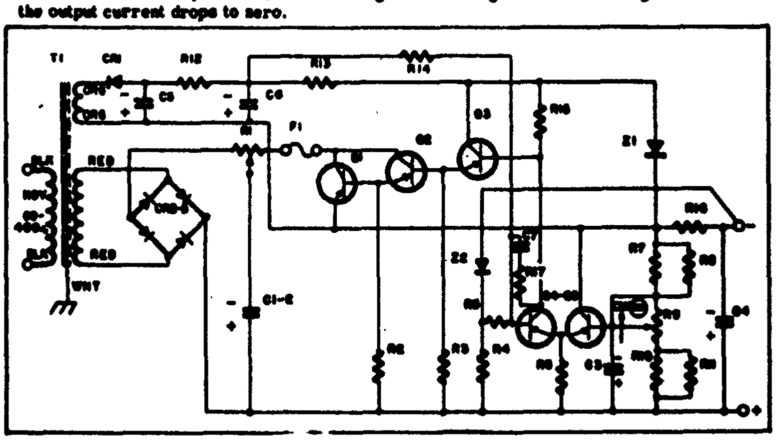


Fig. Circuit Schematic

VI MAINTENANCE

6-1. CLEANING

The inside of the unit may become coated with dust which impairs proper cooling. Remove the perforated case every few months (depending on dust conditions) and remove any dust accumulation from the case and components. Case removal instructions are printed on the side of the unit.

6-2. CHECK-OUT PROCEDURE; REGULATION & RIPPLE AND IMPEDANCE

For check-out of the 20 Series DC Power Supplies against Dressen-Barnes' Specifications, see Figures 3 and 4.

6-3. MAXIMUM AND MINIMUM OUTPUT VOLTAGE SETTING

The output voltage should swing ±5% or ±10% of the nominal voltage of the power supply. (See Specifications, Page I-6, for individual model numbers and outputs). If the output voltage is too low or too high, it will be necessary to change the values of resistors R7 and/or R10 by changing the value of their shunt resistors R8 and/or R11. Shunting R10 decreases the output voltage and shunting R7 increases the output voltage.

6-4. OVERLOAD PROTECTION

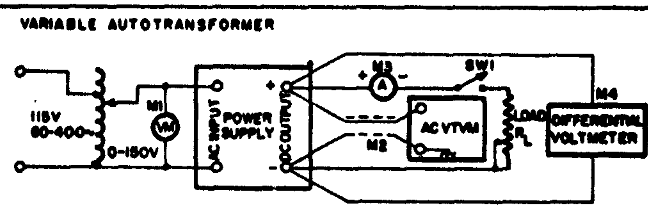
Each model of the 20 Series Power Supplies must be operated with the proper value for fuse, F1. The fuse value is designated on the nameplate of each unit.

6-5. TROUBLE LOCALIZATION

TROUBLE	PROBABLE CAUSE	SOLUTION
No DC output voltage	1. Fuse F1 blown 2. Open transistor Q1, Q2 or Q3.	1. Replace fuse 2. Replace transistor Q1 first. Then Q2 and Q3 respectively.
High DC output voltage	1. Shorted series regulator transistor Q1. 2. Shorted difference amplifier transistor Q5.	1. Replace transistor Q1. 2. Replace matched pair, Q4 and Q5.
DC output voltage erratic high ripple	1. Defective Zener diode Z2 or Z1. 2. Defective resistor R7 or R10.	1. Replace Z2 and/or Z1. 2. Replace R7 and/or R10.
Power supply will not regulate	1. Defective series regulator transistor Q1.	1. Replace defective transistor Q1.

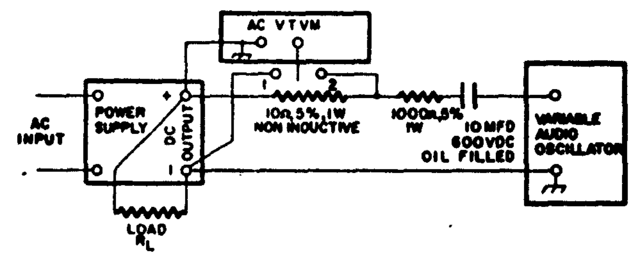
6-6. PARTS REPLACEMENT

Refer to Table I-2 for circuit diagram and replacement parts list of your power supply.



1. Connect the power supply AC input to the variable autotransformer as shown.
2. Connect AC voltmeter M1 across output of variable autotransformer as shown.
3. Connect load resistor R_L to the output terminals of the power supply through switch SW1 and DC ammeter M3. The load resistor R_L should be such that the rated load current is obtained with rated output voltage.
4. Connect a differential voltmeter, M4, DIRECTLY to the power supply output terminals. The differential voltmeter must NOT be connected to the load or to the wires going to the load.
5. Connect an AC vacuum tube voltmeter, M2, with shielded leads to the output terminals of the power supply.
6. LOAD REGULATION CHECK
   a. Adjust variable autotransformer for 115 volts as indicated by M1.
   b. Close load switch, SW1, and adjust load resistor R_L for rated output current as indicated by M3 with the power supply output set at rated voltage.
   c. The load regulation can be measured by alternately opening and closing switch SW1 and observing the voltage change on the differential voltmeter, M4.
7. LINE REGULATION
   With rated output current, SW1 closed, vary the line voltage as indicated by M1 from 105 to 125 volts by means of the variable autotransformer. The line regulation can be observed on the differential voltmeter, M4.
8. RIPPLE
   With the AC input voltage set at 115 volts, rated output current and voltage, the ripple may be observed on the AC vacuum tube voltmeter M2.

Fig. I - 4 Test Setup for Regulation and Ripple Check



1. Connect output of power supply as indicated above. Connections to instrument case grounds should be observed. All connections should be as short as possible.
2. Adjust the power supply output voltage to rated value. In case the rated output voltage exceeds the maximum input voltage rating of any of the test instruments, set the output voltage to a value that does not exceed the DC input rating of the instruments.
3. Set the load resistor so that approximately 90 percent rated load current is obtained.
4. Set the AC vacuum tube voltmeter range to 100 millivolts full scale.
5. With the vacuum tube voltmeter connected to point 2, adjust the output amplitude of the variable oscillator until a reading of 100 millivolts is obtained on the vacuum tube voltmeter.
6. Connect the vacuum tube voltmeter to point 1.
7. The impedance in ohms at the particular frequency setting of the variable oscillator is equal to the vacuum tube voltmeter reading in millivolts divided by 10.
8. For each frequency at which the impedance is measured, recheck the drop across the 10 ohm resistor (vacuum tube voltmeter on point 2) for a 100 millivolt reading.
9. The DC impedance of the power supply is equal to the load regulation of the power supply divided by the rated load current.

Fig. I-5 Test Setup for Impedance Check

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Unclassified Report

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1. Soils -- analysis
2. Strain gages -- development
3. Stress and strain -- measurement

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measurements of small strains.

The gage accurately defines the relative position of two points in the soil and accurately measures the change in spacing of these points when the specimen is strained.

All indications are that the gage is well suited for the measurement of strain in soil and that with further investigation of the effect of gage presence and appropriate modifications to reduce this effect, the gage may be used to reliably measure both static and dynamic strains within a very small gage length.

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