COMPARISON TEST OF THE MICHIGAN AND TESTLAB NUCLEAR DENSITY GAGES

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Synopsis

This report describes tests made to compare the characteristics of the Michigan combination moisture-density gage with a commercial surface gage marketed by the Testlab Corp. of Chicago, in which the radioactive source is located in a probe inserted into the soil sample. The tests were performed on two laboratory samples of soil prepared at controlled values of density. In addition, a third instrument system was formed by using the Michigan gage connected to the Testlab scaler. In this manner, it was possible to determine to what extent, if any, the counting equipment influenced accuracy.

Results of this test show that the commercial instrument gave a greater repeatability than the Michigan instrument. Use of the Testlab scaler did not improve the Michigan gage's performance.

Since the development of the MSHD combination gage many laboratory and field evaluation tests have been conducted, with results that have not always been satisfactory. It was felt that comparison tests with other available nuclear equipment might reveal shortcomings in certain portions of the Michigan instrument system. It also seemed worthwhile to explore the possibility of discontinuing work with the Michigan gage should a commercial instrument prove to be more efficient in terms of accuracy and cost.

Previous tests, in which the Michigan gage was compared with the Nuclear-Chicago surface gage, indicated that the latter gave better results when gravels were tested, but that about equal performance was obtained when the two systems were used with sand.

This portion of Research Project 59 E-21 was undertaken to compare the operating characteristics of the Michigan combination gage with a commercial density gage having a different operating principle. A second objective of this study was to determine what effect, if any, another type of scaler might have on the accuracy of the Michigan gage.

The Michigan instrumentation has been described in Research Report 316 (Research Project 55 H-4) and is shown in Fig. 1. In this system the gage rests entirely on the surface of the material to be measured and is designed so that either density or moisture may be measured, according

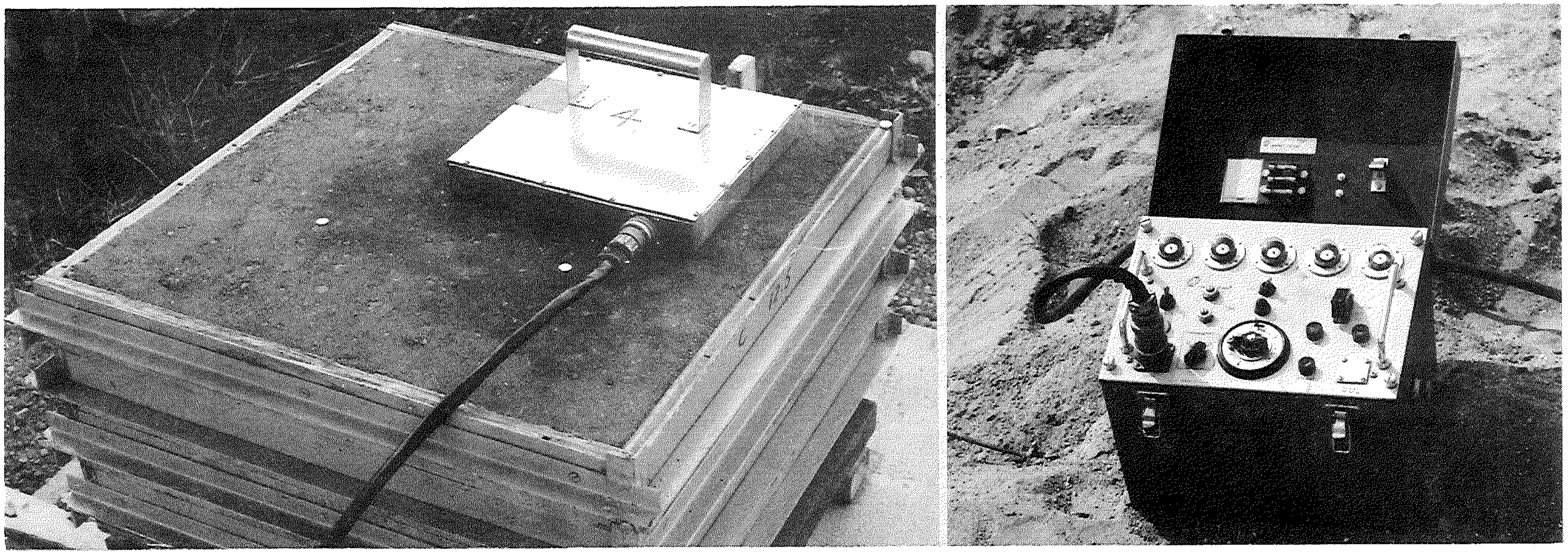
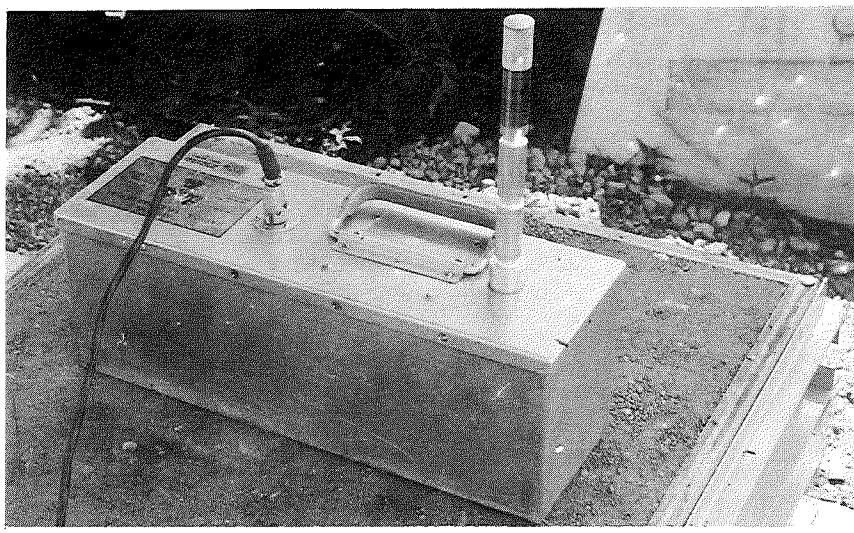
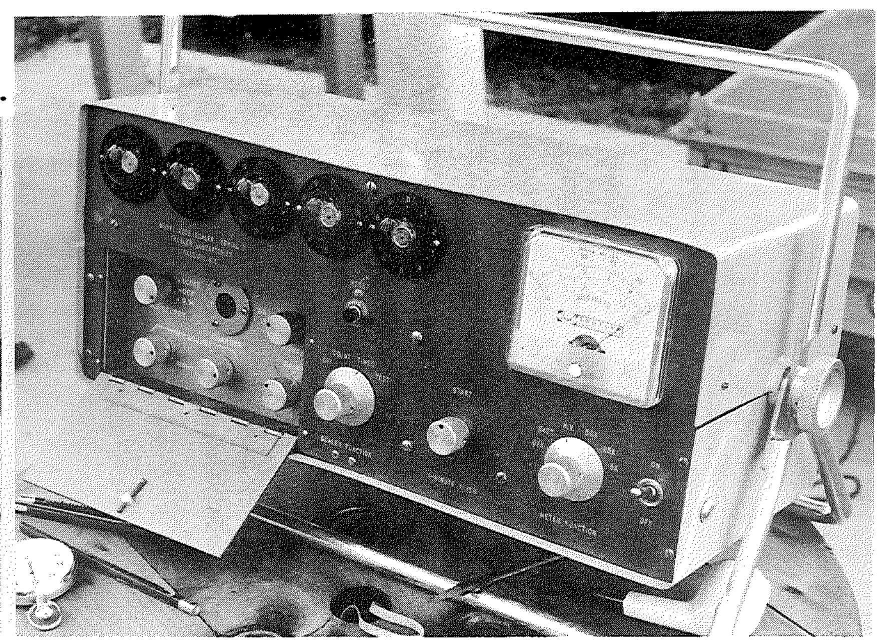


Figure 1. Michigan combination gage (left) and Nuclear-Chicago scaler (right).

Figure 2. Troxler-Testlab gage (below) and scaler (right).





to the position of a switch on the scaler. Radioactive particles backscattered to this gage are counted with a Nuclear-Chicago, model 2800 portable scaler.

The commercial instrument used for comparison in this study was made by Troxler Laboratories of Raleigh, N.C., and is marketed by the Testlab Corp. of Chicago. This instrument system consists of a Model SC-120 Surface Density Gage and Model 2300 Glow-Tube Scaler, as shown in Fig. 2. The gage can be operated entirely on the soil surface, as is the Michigan gage, or the probe containing the source may be inserted into the soil to any distance up to 9 in. For this study the Testlab gage was operated with the source located 5 in. below the soil surface as recommended by the manufacturer's representative.

The more important characteristics of the two instruments are shown in Fig. 3.

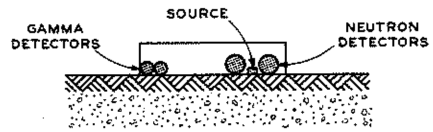
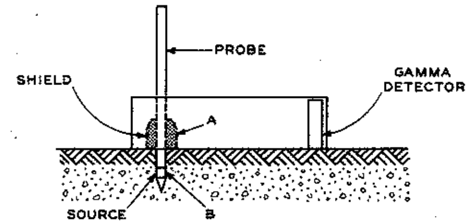
Test Procedure

The tests were conducted in July 1961, on outdoor laboratory soil samples. Due to the limited time that the Testlab equipment was available, it was possible to compare the instruments with only one gravel and one sand sample. Even though this test compares the accuracy of the instruments only for the conditions tested, the relationship of accuracy between instruments should hold for other operating conditions also. Further testing is needed, however, to confirm this.

Soil Samples. The soil samples were compacted in four different frames, each 30 in. square by 3 in. deep and containing one layer of the completed sample. The material in each frame was compacted separately, and then the four frames were stacked to form the complete sample. This procedure minimized density differences between the top and bottom of the 12-in. deep completed sample. Fig. 4 shows the compacting and final weighing of one layer. Fig. 5 shows the finished sample of four layers. In these photographs, the Michigan gage is being used with the Testlab scaler.

The gravel sample was made of a 22A gravel compacted to 130.0 pcf at about 7 percent moisture. The sand sample was compacted to 116.4 pcf at about 10 percent moisture.

Instrument Readings. Fig. 6 shows nine instrument positions as used on the surface of a soil sample during the test. The radial lines indicate the source and detector tube orientation in each of the positions.

GAGES: Characteristics	MICHIGAN COMBINATION GAGE	TROXLER-TESTLAB GAGE
		
Source	5 millicuries of radium-beryllium	3 millicuries of radium-beryllium
Detectors	gamma: two halogen-quenched geiger tubes neutron: two enriched BF_3 proportional tubes	gamma: one halogen-quenched, end window-type geiger tube neutron: one enriched BF_3 proportional tube
Principle	backscatter	backscatter with source in Position "A" direct transmission with source in Position "B"

SCALERS: Characteristics	MICHIGAN (NUCLEAR-CHICAGO) SCALER	TESTLAB (TROXLER) SCALER
Readout	glow tubes	glow tubes or rate meter
Resolution time	35×10^{-6} sec	250×10^{-6} sec
Circuitry	a single type of vacuum tube is used, all rectifiers are semi-conductors	all transistor except glow tubes and corona-type high-voltage regulators
High voltage	continuously variable 700 to 1500 v: both end points regulated by corona regulators	transistorized dc/dc converter provides two regulated high voltage ranges: 350 to 900 v and 1100 to 1500 v
Timer	automatic spring wound, escapement-type	automatic spring wound, escapement-type
Power	rechargeable 6-v wet battery: recharging overnight will replace charge used during full 8-hr day; contains transistorized multi-vibrator transformer power pack; built-in trickle charger operates 115-v 60-c ac	rechargeable silver zinc battery; 30-hr operation without recharge; draws 4 w or less while in operation; operates from 115-v 60-c ac while recharging; charger separate
Weight	27 lb	15 lb; separate charger weighs 12 lb

Figure 3. Systems used in comparison tests.

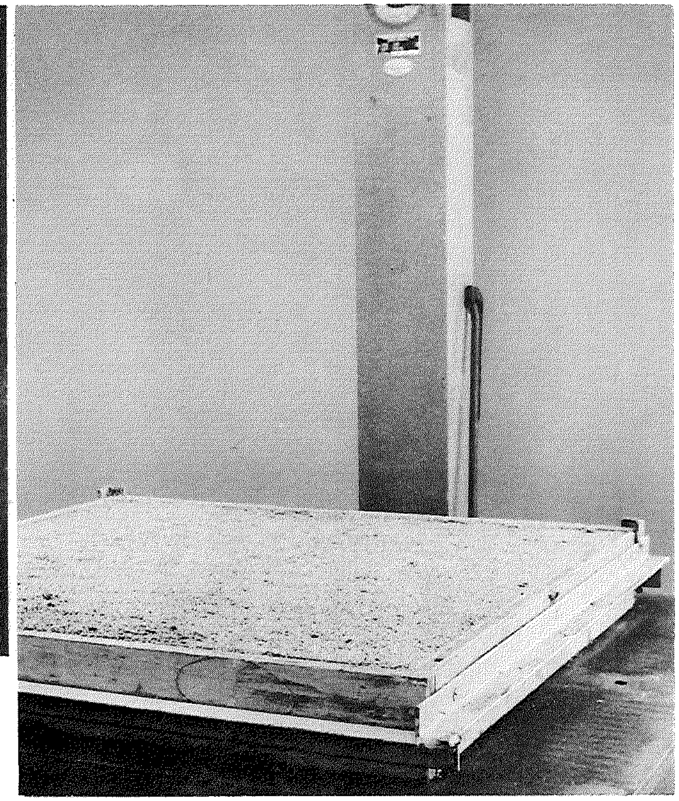
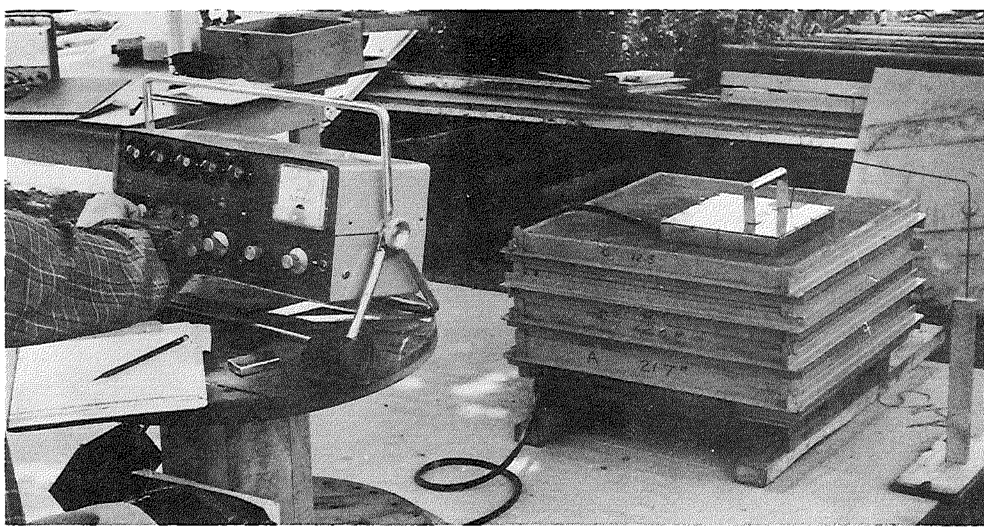
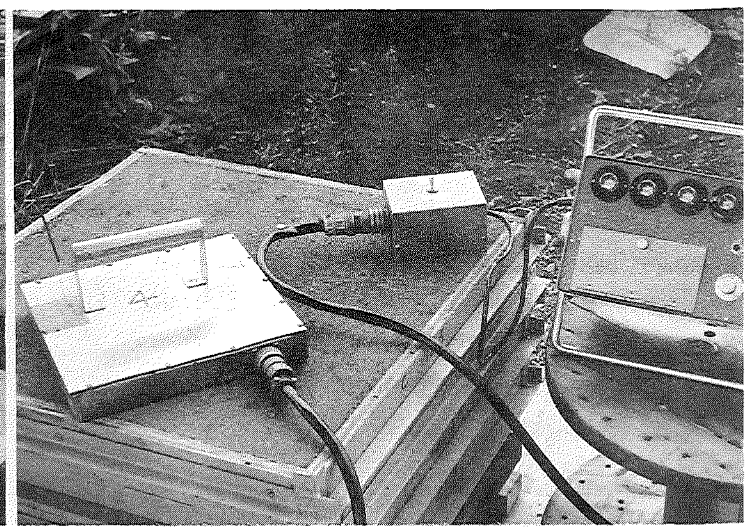


Figure 4. Compacting (top) and weighing one sample layer (right).

Figure 5. Testlab scaler and Michigan gage on a finished four-layer soil sample (below and right).





Because the Testlab gage disturbs the sample (the probe is driven 5 in. into the soil) and the Michigan gage does not, all readings were obtained using the Michigan gage first. During the test a gage was positioned with the source at Location A (Fig. 6), and oriented to one of the three rotational positions. Five readings were obtained without moving the gage. This procedure was repeated for the other two positions associated with Location A. Readings were similarly obtained in Locations B and C. In this manner a total of 45 readings were obtained for each instrument on the gravel sample. The same procedure was repeated using the Michigan gage and Testlab scaler combination and then the Testlab gage and scaler. A similar procedure was used on the sand sample except that the Testlab instrument was used at only two locations instead of three.

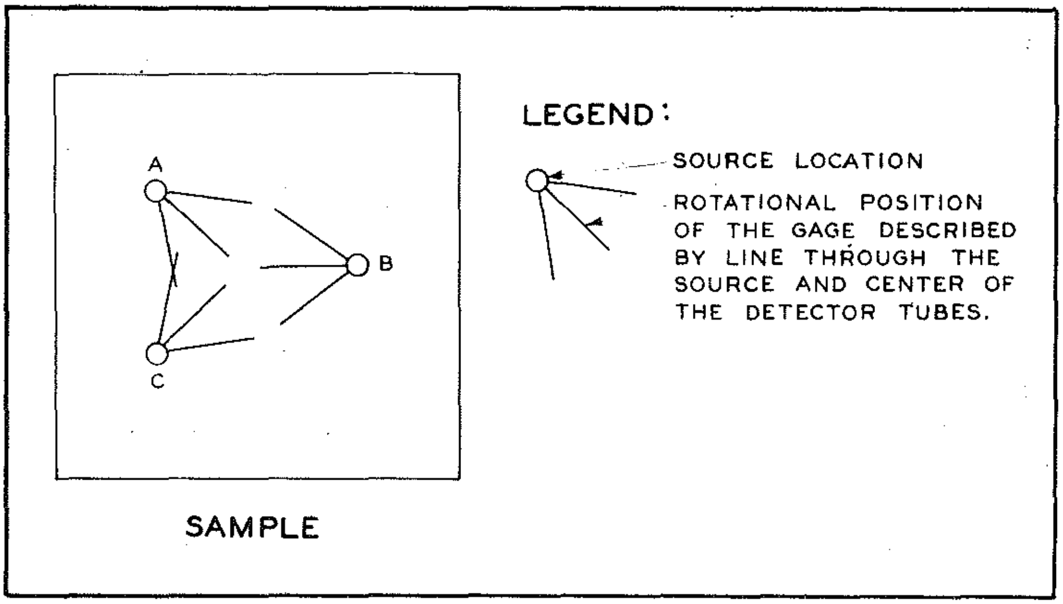


Figure 6. The three source locations and nine gage positions on the sample surface.

Each instrument is different in source strength, number of detectors, and geometric arrangement, and for this reason count rates for the two instruments are not the same on a given sample. By using two samples at different densities, a calibration curve was established for the Testlab instrument system so that nuclear readings, in counts per minute, could be converted to density values expressed in pounds per cubic foot (Fig. 7). The calibration curve from previous work was used for the two systems employing the Michigan gage. The Laboratory's test experience to date indicates that the slope established for a gage does not change significantly with either time or with a different scaler.

Data Analysis

Due to the random emission of radioactive particles from the source (random with respect to direction, energy, or both), repeated readings obtained on the same sample were not identical even for any one instrument. Such repeated readings have an average value and a variation of values which are characteristic of the particular instrument. The smaller the variation, the better the instrument. It was upon this basis that the three instrument systems were compared.

A statistical parameter, called the standard deviation, was computed for each of the three instrument systems. The standard deviation is a measure of the variation of values obtained in a set of data when all values are obtained under the same conditions, and is useful for comparing different sets of data. Mathematically, the standard deviation may be expressed as

$$S_y = \sqrt{\frac{\sum_{i}^{n} (y_i - \bar{y})^2}{N}}$$

where

S_y = standard deviation

y_i = the value of the i^{th} item in the sample where i has values 1, 2, 3 . . . N

$\bar{y}$ = average value of N items, and

N = number of items in the sample.

As a first analysis the standard deviation was computed from the data for each instrument system, in units of counts per minute. In this analysis, all 45 readings for each instrument were used with the gravel sample to compute an overall standard of deviation, S_y counts per minute, for each of the three instrument systems. Similarly, the 30 readings obtained on the sand sample with the Testlab system were used to compute the standard deviation for this material.

For comparison purposes, S_y values were converted to density deviations, S_x, expressed as pounds per cubic foot, by dividing S_y by the slope, m, of the pertinent calibration curve. This conversion, $S_x = \frac{S_y}{m}$, is shown graphically in Fig. 7. The values of S_X determined in this analysis are given in Table 1.

This initial analysis was based on the assumption that the soil sample was of uniform density. A closer investigation of the data, however, strongly indicated this assumption to be invalid and that the values of S_X in Table 1 include variations due to density differences between gage positions as well as those inherent in the instrumentation itself.

TABLE 1
DENSITY VARIATIONS, AS STANDARD DEVIATIONS, RESULTING FROM SOIL AND INSTRUMENT FACTORS
(First Analysis)

System	Soil Type	Total 1-min Readings	Density Deviations (S_X), pcf
Michigan	Gravel	45	1.78
Michigan gage and Testlab scaler	Gravel	45	1.86
Testlab	Gravel	45	1.69
Testlab	Sand	30	1.10

A second analysis was made to compare variations due to the instrumentation alone. Each instrument was oriented in nine different test positions on the gravel sample. For the Testlab instrument with the sand sample, however, only six positions were used. In each position, five consecutive readings were obtained without moving the instrument. For each group of five readings, the range (maximum-minimum) is tabulated in Table 2. The density values shown in Table 2 were determined from count rates and the calibration curves.

Test Results

The results of this test show the Testlab instrument system to have better repeatability and more sensitivity to small density changes than the Michigan instrument system. The performance of the Michigan gage was not improved by using it connected to the Testlab scaler, indicating that the difference in performance is due to differences between gages rather than scalers.

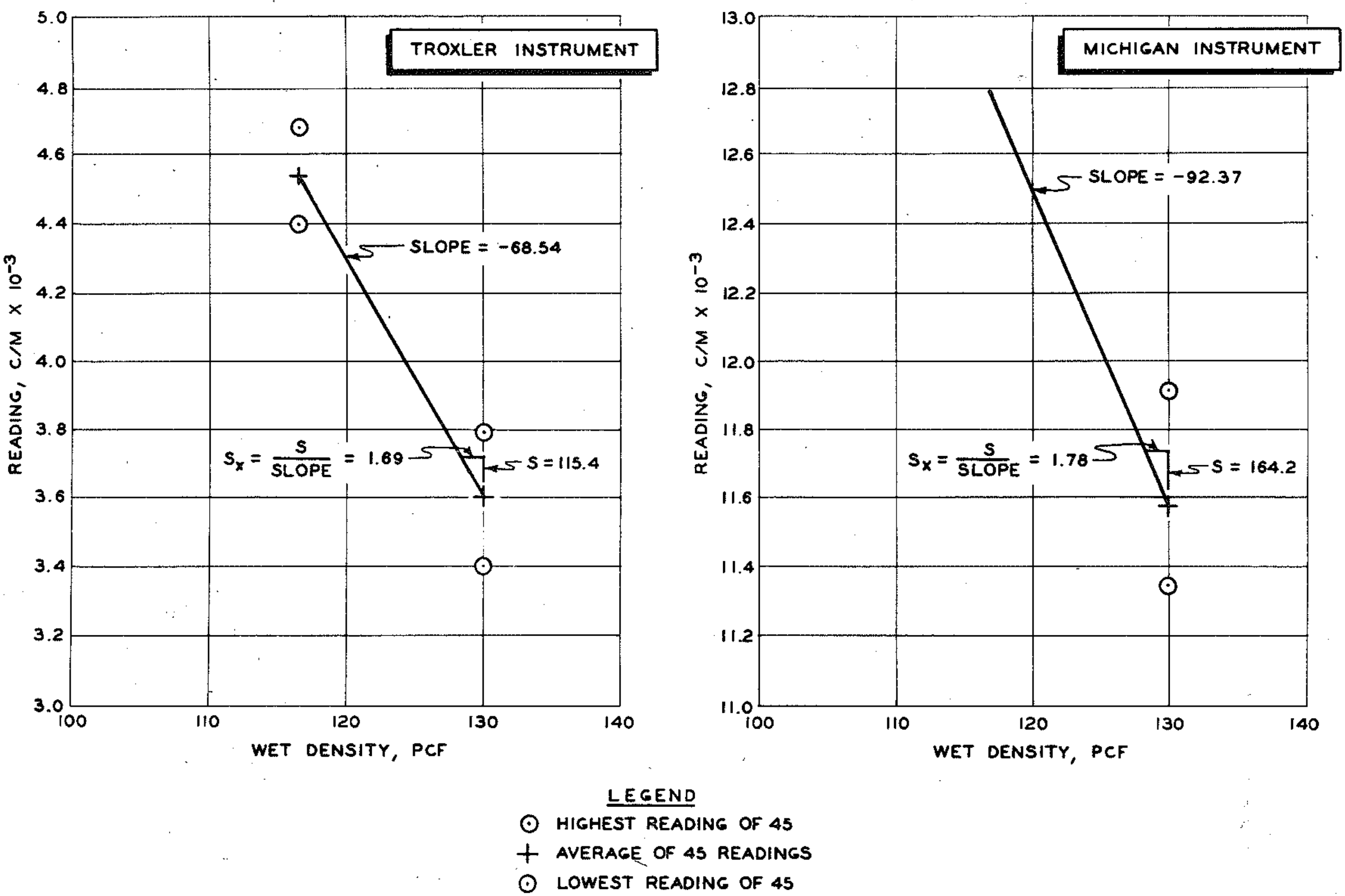


Figure 7. Density calibration curves for the two test gages.

The first method of analysis (in which soil density variations were a factor) showed no significant difference in performance of the three instrument systems. This is indicated by the density deviations, S_X, in Table 1. Results of the second method of analysis (in which operation of the instrument was the only variable), however, showed the Testlab instrument to be more accurate than the Michigan instrument (Table 2). Data in this table also shows that the performance of the Michigan gage was not improved by using it with the Testlab scaler.

TABLE 2
DENSITY VARIATIONS, AS RANGES, RESULTING FROM INSTRUMENT ERROR
(Second Analysis)

System	Soil Type	Total 1-min Readings	Density Range, pcf, for 9 gage positions*									Average Range, pcf
			1	2	3	4	5	6	7	8	9	
Michigan	Gravel	45	3.9	2.5	3.6	3.4	3.8	4.0	3.9	2.6	2.3	3.3
Michigan gage and Testlab scaler	Gravel	45	1.7	5.2	5.2	4.1	3.0	2.6	2.3	3.4	3.0	3.4
Testlab	Gravel	45	1.3	0.9	2.2	0.9	1.8	1.5	1.4	1.8	2.0	1.5
Testlab	Sand	30	2.0	1.9	1.1	1.7	1.3	1.3	---	---	---	1.6

* The nine positions for any one gage were not congruent with those for any other gage.

The apparent contradiction of results obtained by the two methods of analysis can be reconciled by compiling the information from both analyses so that the different sources of variation involved in the two methods can be considered. In the first analysis, the total variation for any one instrument is composed of two sources--soil density differences between the individual nine gage positions and errors of instrumentation. The total error in the second analysis is simply the instrument error, since instrument error alone is involved when a series of consecutive readings are obtained without movement of the gage between readings. The difference between S_X values for the first and second analyses is due to the influence of soil density variations among the nine gage positions.

This pooling of the two seemingly different analyses is represented in Table 3 and is analogous to analysis of variance methods that were used in this third or summary analysis of the data.

As shown in Table 3, all instruments performed about the same when considered on the basis of the overall soil sample (first analysis). The elimination of the effect of density differences between positions (second analysis) improves all instruments but seems to have the most influence on the Testlab instrument, indicating that this equipment may have greater sensitivity to small changes in soil density. The Michigan instrument was less influenced by the position changes because the instrument error (instrument variations) is large enough to conceal variations introduced by small density changes.

Subsequent work with the Michigan gage has revealed sudden changes in average count rate when the instrument is operated on a standard block of constant density. This change in operating level was not apparent for any of the instruments during these tests. Further testing would be required to determine if this change in operating level is also present in the Testlab equipment.

TABLE 3
DENSITY VARIATIONS AS STANDARD DEVIATIONS:
SUMMARY AND SOURCES OF VARIATION*
(Third Analysis)

System	Soil Type	Density Deviation (S_X), pcf	
		Due to Instrument Error plus Density Difference Between Positions	Due to Instrument Error Only
Michigan	Gravel	1.80	1.07
Michigan gage and Testlab scaler	Gravel	1.88	1.17
Testlab	Gravel	1.71	0.65
Testlab	Sand	1.12	0.64

* Table derived from an analysis of variance performed on the data for each instrument. Values in third column correspond to density deviations in Table 1; values in fourth column to average ranges in Table 2.

Conclusions

Based on the limited amount of data obtained in this study the following conclusions appear warranted:

1. The Testlab instrument and the Michigan instrument performed equally well when uniform density of the soil sample was assumed, as in the first analysis.

2. The Testlab gage had a greater degree of accuracy than the Michigan gage when the comparison was based on repeatability of consecutive readings in which the gage remained in one position with no movement between readings.

3. The performance of the Michigan gage was not improved by using it connected with the Testlab scaler.

4. The laboratory soil samples were quite probably not of uniform density for either sand or gravel.

5. The Testlab scaler has several advantages over the Nuclear-Chicago scaler presently being used with the Michigan gage. These are:

a. Built-in rate meter useful for rapid density or moisture determinations and rapid checks of instrument performance on standards.

b. Built-in voltmeter to register battery voltage under operational load and high voltage supplied to the radiation detection tubes. This feature enables the operator to perform checks on the instrument in the field that can be done only in the laboratory with the Nuclear-Chicago scaler. This feature may be of more value, however, for research studies than for field construction operations.

c. Lighter weight because it is transistorized and the battery charger is a separate unit that does not have to be carried into the field.

6. A longer range evaluation program should be conducted with the Testlab instrument in order to reveal characteristics, either good or bad, that may not have been revealed in this relatively brief study.

APPENDIX

SUMMARY OF GAGE TEST RESULTS
Readings in Counts per Minute

Instrument	Soil	Locations								
		A			B			C		
		1	2	3	4	5	6	7	8	9
MSHD Gage and Scaler	Gravel	11625	11435	11643	11617	11478	11516	11722	11958	11595
		11346	11396	11431	11469	11705	11417	11860	11801	11614
		11538	11370	11385	11490	11536	11691	11731	11831	11636
		11537	11541	11386	11461	11742	11415	11969	11839	11547
		11397	11409	11441	11702	11589	11613	11796	11771	11469
Troxler Gage and Scaler	Gravel	3426	3538	3526	3556	3734	3656	3686	3481	3795
		3415	3522	3534	3562	3794	3757	3691	3585	3654
		3399	3518	3514	3544	3664	3712	3680	3464	3754
		3490	3559	3644	3595	3717	3734	3748	3460	3739
		3435	3497	3493	3615	3615	3670	3769	3545	3758
Troxler Scaler MSHD Gage	Gravel	11341	11611	11048	11274	11445	11419	11711	11688	11356
		11295	11269	11299	11498	11429	11538	11661	11604	11481
		11252	11418	11234	11383	11385	11480	11748	11803	11288
		11371	11639	11415	11378	11339	11478	11548	11789	11269
		11249	11264	11109	11494	11550	11588	11552	11562	11470
Troxler Gage and Scaler	Sand	4406	4553	4657	4617	4499	4508			
		4539	4541	4672	4583	4455	4553			
		4485	4422	4682	4553	4471	4485			
		4448	4474	4645	4590	4527	4468			
		4517	4473	4608	4669	4552	4559			