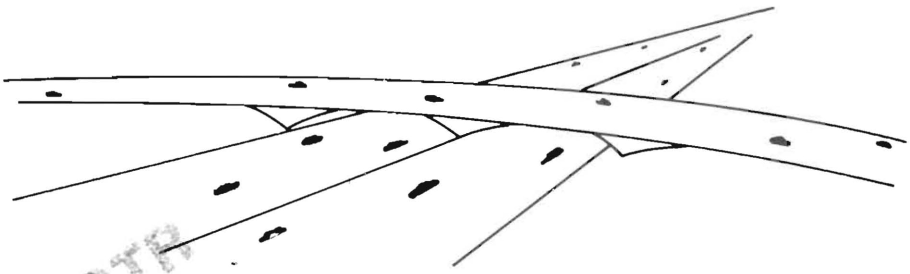


DEPARTMENTAL RESEARCH

Report Number 37 - 1

AN EVALUATION OF THE MOISTURE AND DENSITY ROAD LOGGER UNIT

PROGRESS REPORT

By

Justin M. Bingham
and
James R. White Jr.

Research Project 1 - 6 - 62 - 37

CONSTRUCTION DIVISION

TEXAS HIGHWAY DEPARTMENT

An Evaluation of the Moisture and Density Road Logger Unit

by

Justin M. Bingham
Supervising Field Engineer

James R. White, Jr.
Associate Office Engineer

Progress Report No. 37-1

District Evaluation of Nuclear Type
Moisture and Density Instruments
Research Project 1-6-62-37

Conducted by

Construction Division
Texas Highway Department
In Cooperation with the
U. S. Department of Commerce, Bureau of Public Roads

October 1965

ACKNOWLEDGEMENTS

The writers wish to thank Messrs. W. E. Carmichael, G. P. Munson, Jr., and others of District 12, Texas Highway Department, for making available the trained personnel, equipment and facilities needed for making this evaluation program possible.

Special acknowledgement is given to Messrs. Daniel N. Hanna Jr. and James N. Anagnos, formerly of District 12, who supervised and conducted the field operations and provided most of the data used in this report.

LIST OF FIGURES

An Evaluation of the Moisture
and Density Road Logger Unit

TABLE OF CONTENTS

ABSTRACT

This report covers the developments and accomplishments derived from two periods of study involving the Road Logger Moisture and Density Logging Unit. The major objectives of this study were to determine the construction control capabilities of the Road Logger and to investigate the feasibility of using this equipment to field calibrate the smaller, portable-type nuclear density gauges being used on a limited basis by the Texas Highway Department.

The initial Road Logger investigation was devoted almost entirely to establishing a correlation between Road Logger and conventional measurements of moisture content and density in base courses and subgrades. Attempts were also made during this investigation to establish a relationship between Road Logger wet density values and the count-ratio values of the nuclear density gauge.

The results of the correlation study indicated reasonably good correlation between Road Logger and conventional measurements of moisture content and wet density, however in most cases the Road Logger values exceeded those of the conventional tests. In the more uniform base materials that were tested, substantial agreement of dry density values could be obtained by applying a correction factor to the Road Logger measurements of moisture content.

Even though correlation to some extent was obtained between count-ratio of the portable nuclear gauge and Road Logger wet density, this method of calibration was only partially successful. Differences in sample size actually investigated and variations of wet density in the compacted materials apparently contributed to the observed spread in test

results. This spread in test results made it difficult to establish accurate reference curves for use with the smaller gauges.

During the second period of investigation, the Road Logger unit was used on a number of construction projects in an effort to evaluate its performance as construction control equipment. Such factors as mobility, maneuverability, and cost of operation under actual construction project conditions were studied. Only base courses and finished subgrade layers were tested during this period of investigation. Compaction control of embankment construction was not undertaken because of the relatively uneven or rough surfaces exhibited by most embankment layers and the sensitivity of the Road Logger models used in this study to rough surfaces.

I. INTRODUCTION

This research study, involving the Lane-Wells Road Logger, was a part of a program to evaluate nuclear methods of measurement of in-place moisture content and density in highway base course construction. The evaluation was conducted at the district level by the Texas Highway Department in cooperation with the United States Department of Commerce, Bureau of Public Roads. Two separate, but related studies involving the Road Logger were made.

The first study began in June, 1964, and extended over a period of approximately two months. The major portion of this study consisted of comparing Road Logger density measurements with those obtained using the rubber-balloon volumeter and core displacement methods. Road Logger moisture content measurements were also compared to those obtained by the oven-drying method. In addition, a special study was conducted during this first period which involved attempts to field calibrate a portable-type commercial nuclear gauge by relating count-ratio nuclear readings to Road Logger wet density measurements.

The second study began in December, 1964, and extended over a period of three months. The primary objective of this investigation was to obtain information relating to such factors as Road Logger mobility, maneuverability, and cost of operation under actual construction project conditions.

Most of the work described in this report is based on measurements made on projects located in Harris, Galveston, Fort Bend and Brazoria Counties on the Texas Gulf Coast. The materials that were tested consisted of mixtures of sand and shell, gravel screenings produced commercially from sources located along the Colorado River, burned clay, processed gravel, and various clays used as subgrade materials. Some of these materials had been treated with relatively small percentages of either portland cement or hydrated lime. This wide selection provided an opportunity to use the Road Logger measurements as a means of studying variations in density in the compacted layers. The variations in density in these materials had appeared to be of greater magnitude than had been observed in the crushed limestones and sandstones commonly used in other areas of the State.

This study was limited to layers of material of at least 6 inches in depth. No attempts were made to determine the depth of material actually measured by the Road Logger. Based on information provided by the manufacturer, it was assumed that layer depths of 6 inches would serve satisfactorily for comparing Road Logger and Conventional measurements.

II. ROAD LOGGER EQUIPMENT

Two models of the Road Logger were used in this research study. Both models utilized a 0.43-curie cobalt 60 gamma ray source for density measurement and a 5-curie plutonium-beryllium neutron source for moisture measurement. According to the manufacturer, the detection system for density was designed to discriminate against low energy gamma rays which has the effect of eliminating chemical or elemental composition as a factor in density measurement.

The Road Logger has been described by the manufacturer as a mobile, self-contained nuclear logging unit which provides an instant recording or log of moisture content and wet density while travelling at a predetermined speed over the roadway. A dual-channel strip chart recorder and associated electronic equipment are utilized to provide this continuous record for the portion of the roadway traversed. Information furnished by the manufacturer indicates that the units used in this study record measurements of moisture content for a strip of roadway approximately 12 inches wide, 6 feet long and about 8 inches deep, and measurements of wet density for a strip of roadway approximately 15 inches wide, 7 feet long, and 6 to 7 inches deep when traveling at the rate of 150 feet per minute. This could be interpreted to mean that any point on the log would be an integration of the high and low values within the volumes defined above. Each infinitesimal portion of the log is interpreted to represent the average density of the material layer for a strip approximately 7 feet in length behind the immediate position of the Road Logger.

Depth of density measurement data for the Road Logger unit and the relative influence of each inch of material as determined by the manufacturer are summarized in the following table:

Depth Interval	Approximate Relative Influence	Accumulative Relative Influence
0 to 1 inch	27%	27%
1 to 2 inches	30%	57%
2 to 3 inches	20%	77%
3 to 4 inches	12%	89%
4 to 5 inches	6%	95%
5 to 6 inches	4%	99%
6 to 7 inches	1%	100%

Using the data from the above table, the Road Logger density measurements could be expected to correlate best with conventional measurements extending from the surface to a depth of 4 to 5 inches below the surface.

Measurement of moisture content by the Road Logger is reported by the manufacturer to be to a depth of approximately 8 inches. The depth of measurement could be expected to be greater in materials of low moisture content than in materials of relatively high moisture content. The moisture located near the surface has more influence on the total moisture measurement than that near the bottom of the investigated range.

As previously stated, two models of the Road Logger were used in this research study. A production prototype unit was used during the first evaluation period, during which time correlation and calibration studies were conducted. Another model, employing some improved design features, was used during the second study or the construction control phase. This improved model contained the same instrumentation as the previous model, but was mounted on a light commercial-type truck which provided operational characteristics comparable to vehicles normally used in highway construction operations. The new model proved to be more rugged, more mobile and maneuverable than the previous model. Narrow width sections of roadway, such as shoulders, could be logged more accurately due to the narrow wheel base dimensions of the sensing equipment carriages. This feature contributed to a reduction in variation in stand-off (air-space) between the sensors and the road surface. The vehicle was able to travel between projects at speeds of approximately 55 miles per hour which permitted more time for actual testing.

Calibration of the Road Logger is maintained through the use of moisture and density standards which are carried on the vehicle and are used for calibration prior to beginning each operation. This type of standardization provides control of the overall response of the Road Logger detection and electronic assemblies, and ties field calibration to a laboratory developed calibration curve.

The Road Logger is designed for operation by one man. An operator can be trained to operate the unit safely and efficiently in a short period of time.

III. CORRELATION AND CALIBRATION STUDIES

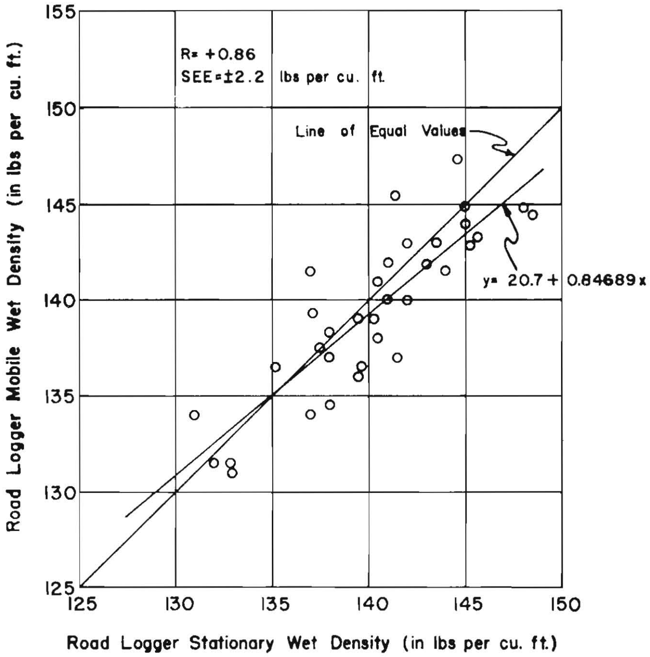
Description of Measurements

In order to use the Road Logger for field calibrating the small nuclear systems and to justify further investigation of its usefulness as construction control equipment, it was desirable to establish initially the relationship between Road Logger measurements and those obtained using conventional methods. As a means of doing this, the Road Logger was first operated over predetermined lengths of roadway at a speed of approximately 150 feet per minute. As "mobile" measurements for moisture content and wet density were being recorded, high and low plateaus were noted and their locations marked for further testing by the Road Logger in a "stationary" position. These stationary readings provided moisture content and density values for areas approximately 15 inches in width by 11 inches in length and for depths of 6 to 8 inches, depending upon the characteristics of the material being tested. After the stationary measurements were taken, volumeter measurements and/or cores were obtained at precisely the same spots. Cores from the cement-treated materials were obtained with mechanized drills equipped with diamond-tipped bits. These cores were coated with paraffin and their density determined using the water displacement method.

Correlation of Test Results

Comparison of Mobile and Stationary Measurements. In order to establish a relationship between Road Logger mobile and stationary wet density measurements, comparisons were made for the gravel screenings and sand-shell materials and the results are shown in Figures 1 and 2. Of some 141 comparisons made for these materials, 80 percent of the mobile measurements were within 3 pounds per cubic foot of stationary measurements made at the same spot. Since the

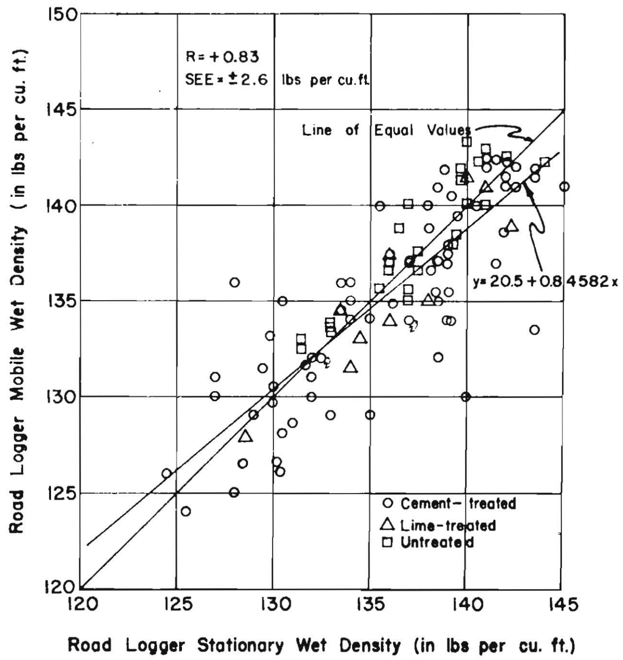
GRAVEL SCREENINGS
(CEMENT-TREATED)



COMPARISON OF MOBILE Vs. STATIONARY WET DENSITY

Figure 1

SAND-SHELL



COMPARISON OF MOBILE Vs. STATIONARY WET DENSITY

Figure 2

mobile measurements represented volumes of approximately 5 cubic feet and the stationary measurements represented volumes of approximately 0.5 cubic feet, at least part of the differences in wet density could be attributed to variations in density which existed in the compacted layers. Another factor which is believed to have contributed to these differences was variations in stand-off or air-space between the Road Logger sensing unit and the surface of the base course. Stationary tests are considered to be more affected by these variations than are the mobile tests.

Comparison of Road Logger and Conventional Measurements. Comparisons were made of the Road Logger stationary measurements and those made using the volumeter and oven-dry methods for the several types of compacted base course materials and subgrade soils. The results are shown graphically in Figures 3 through 7. These graphs indicate that the average Road Logger measurements of wet density were generally 1 to 5 pounds per cubic foot higher than those obtained using the volumeter. Road Logger measurements of moisture content averaged 2 to 3 pounds per cubic foot higher than moisture content obtained by the oven-drying method. Figure 8 shows graphically the relationship of Road Logger and conventional dry densities as determined from the data shown in Figure 3. This graph indicates the need for applying a correction factor to Road Logger moisture values in order to obtain agreement of dry density measurements.

Dry densities in cement-treated sand-shell material, as determined by the core displacement method, were compared with Road Logger dry density measurements and are shown graphically in Figure 9. Of the 50 comparisons shown, 75 percent of the Road Logger values are within 3 pounds per cubic foot of the core values.

Variations in the compacted layers and the differences in volumes of material measured, appear to be the major cause of the spread in wet density measurements. The Road Logger stationary measurements for wet density represented volumes of approximately 0.5 cubic feet, whereas the volumes represented by conventional measurements were approximately 0.1 cubic feet. The Road Logger credits more weight to the upper portion of a compacted layer than it does to the bottom portion, whereas the volumeter and core displacement methods credit equal weight to each increment of depth investigated.

The correlations established for the over-dry method and the Road Logger stationary method of moisture measurement show that the Road Logger values were higher in practically every case. It is believed that the two major factors contributing to these differences were:

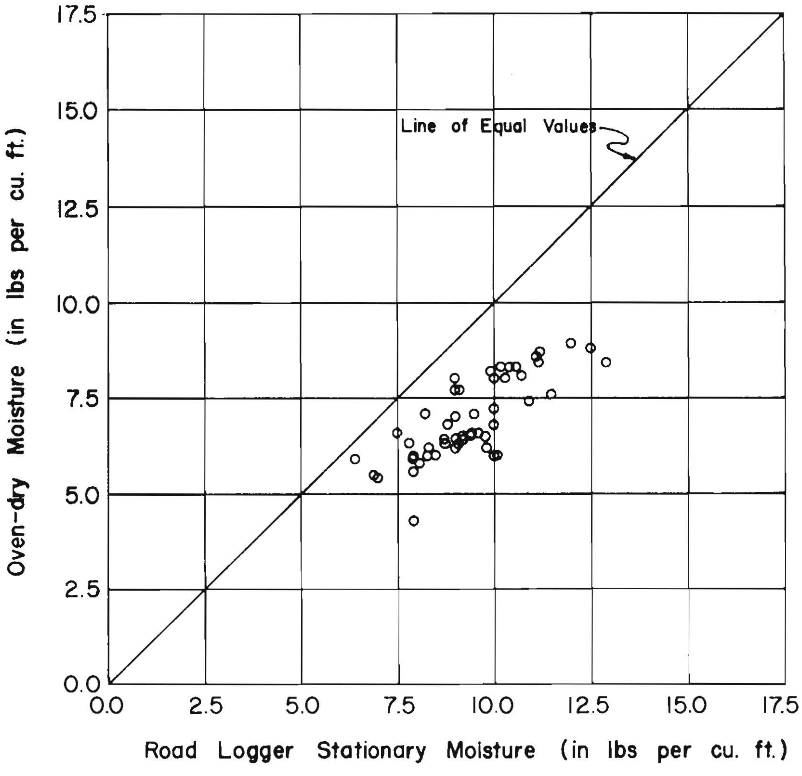
(1) Nuclear (Neutron) penetration through some of the 6 inch layers of material and into the very moist subgrade soils which are common to the Texas Gulf Coast area.

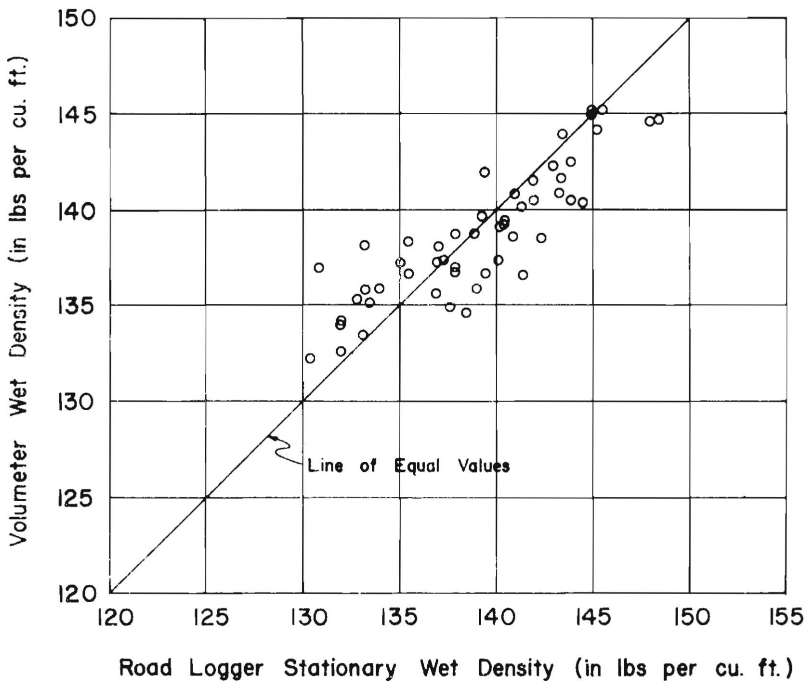
(2) Nuclear detection of hydrogen (bound-up moisture) present in the chemically treated layers which was not measured by the oven-dry method.

In actual use of the Road Logger for construction control, adjustment to a one to one correlation with conventional measurement for both moisture content and wet density can be made, either during initial calibration of the Road Logger or when computations for dry density are made.

GRAVEL SCREENINGS

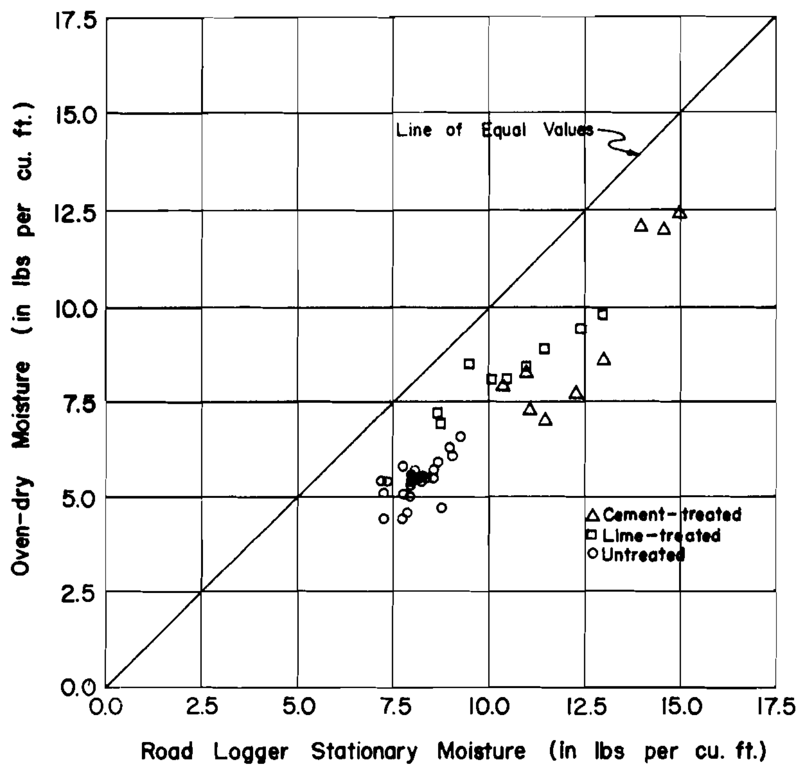
(CEMENT-TREATED)

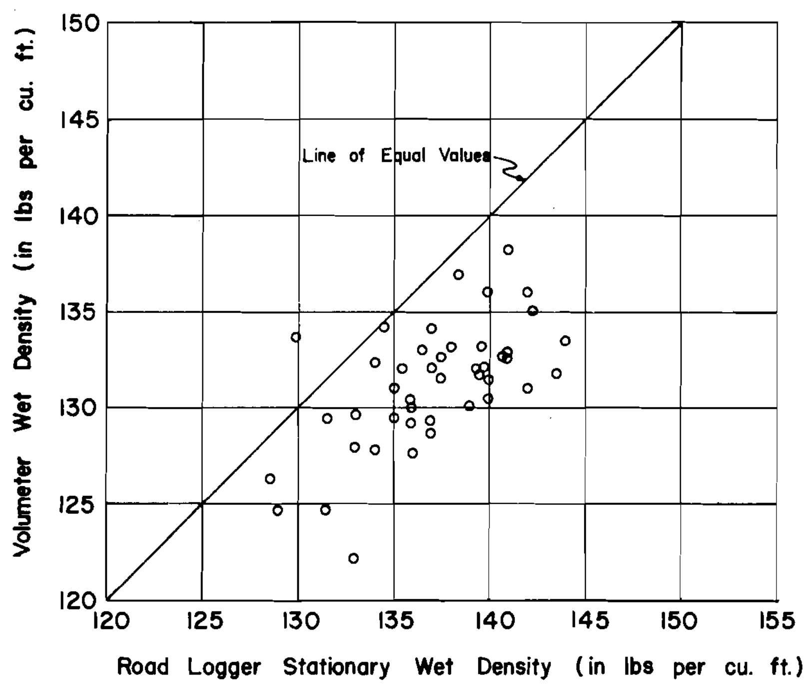




COMPARISON OF ROAD LOGGER STATIONARY Vs. CONVENTIONAL METHODS

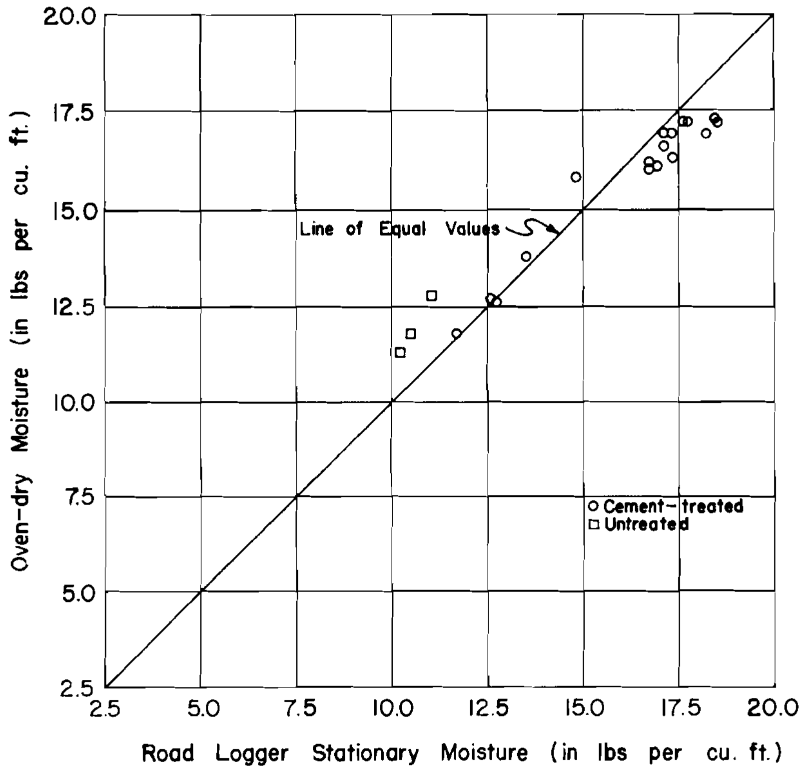
FIGURE 3

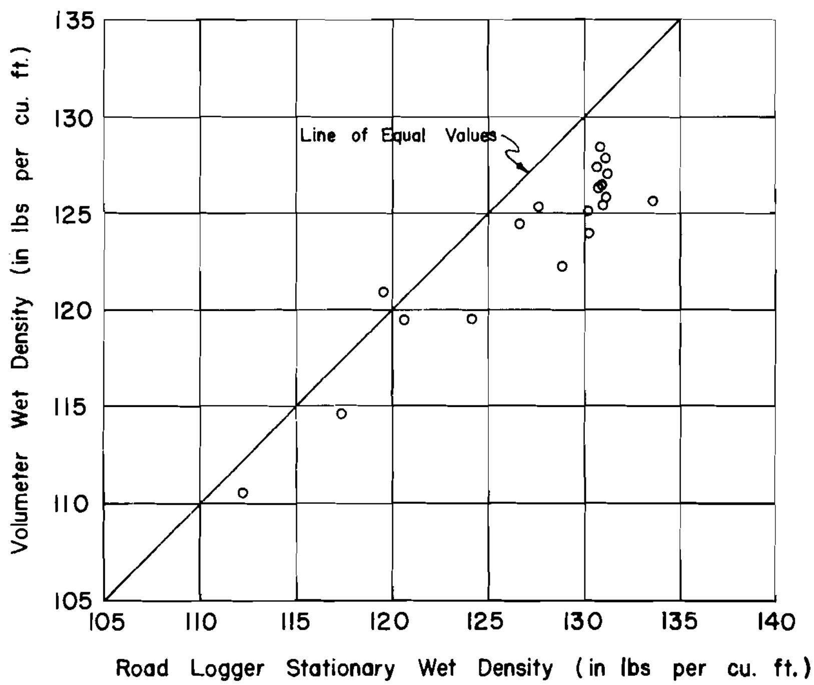




COMPARISON OF ROAD LOGGER STATIONARY Vs. CONVENTIONAL METHODS

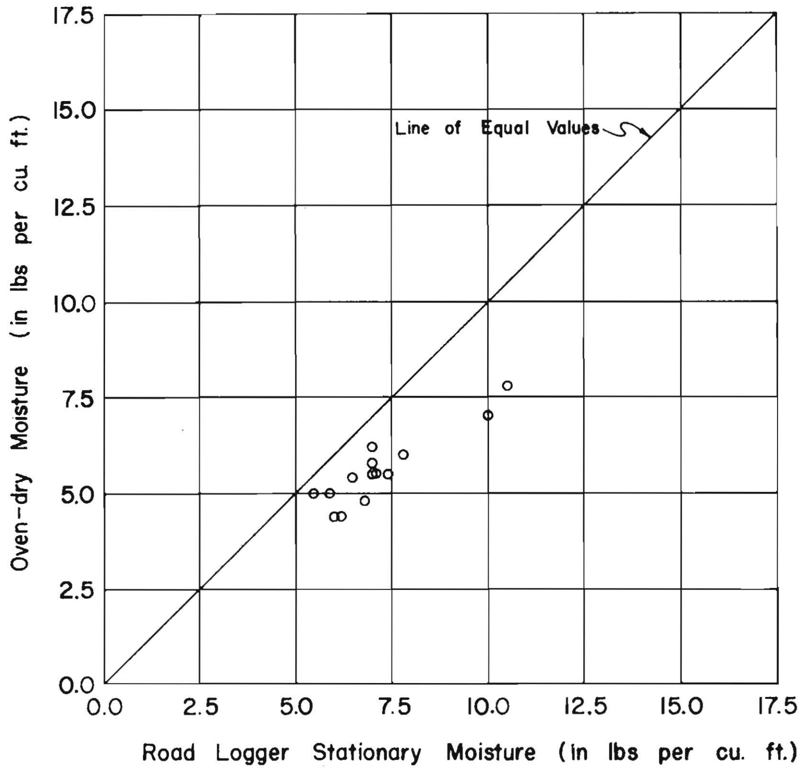
FIGURE 4

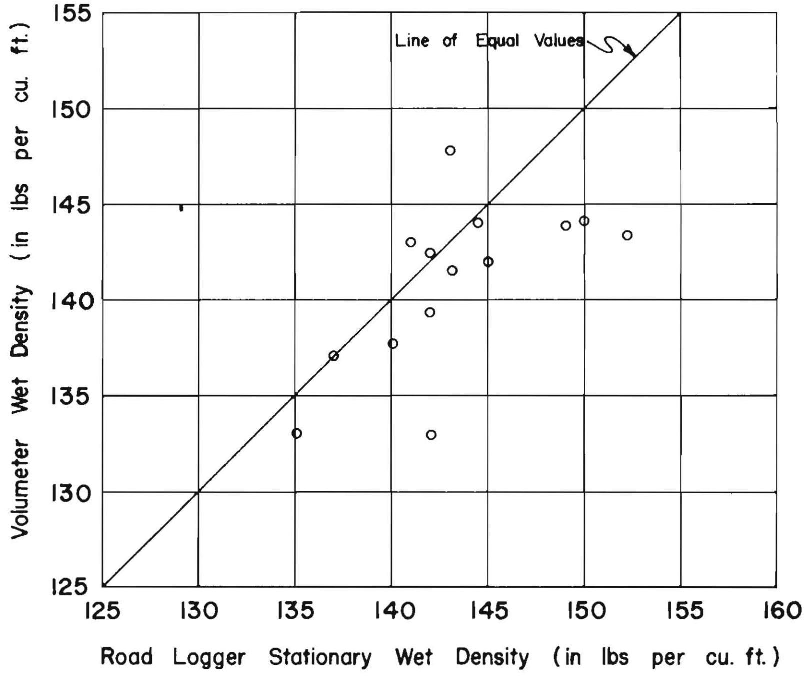




COMPARISON OF ROAD LOGGER STATIONARY Vs. CONVENTIONAL METHODS

FIGURE 5

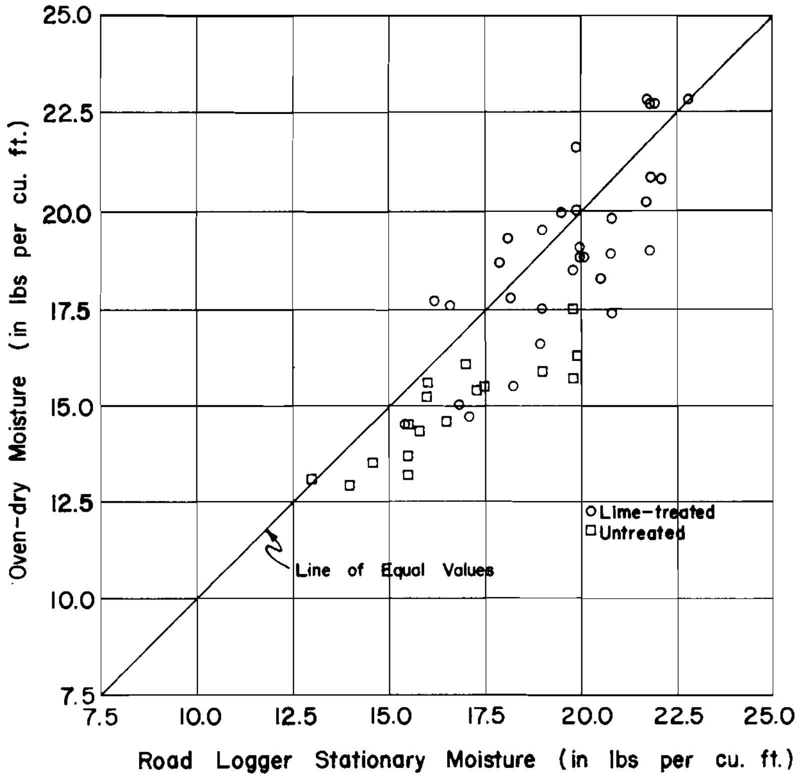


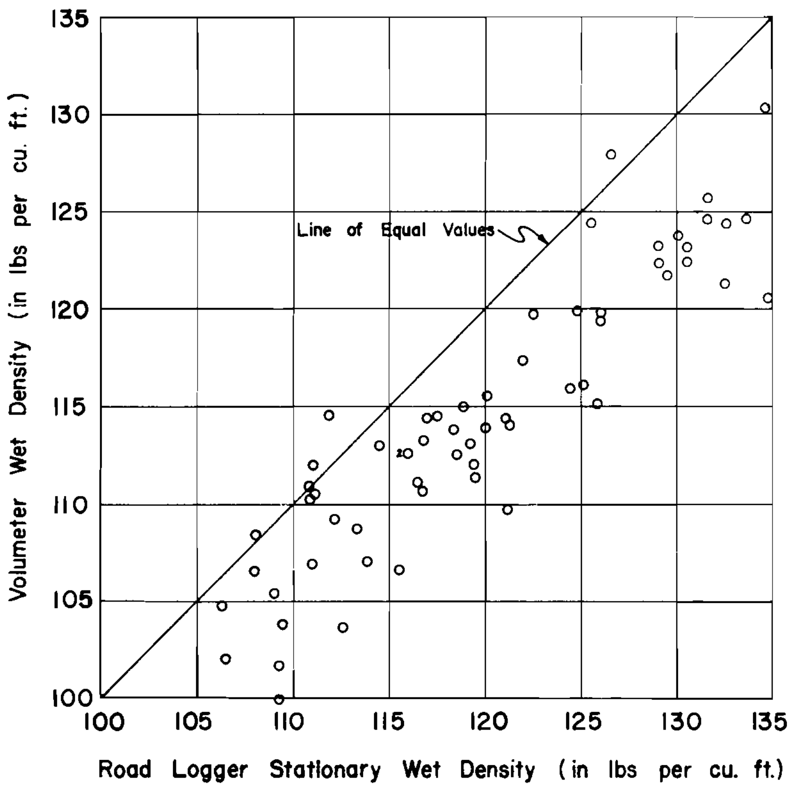


COMPARISON OF ROAD LOGGER STATIONARY Vs. CONVENTIONAL METHODS

FIGURE 6

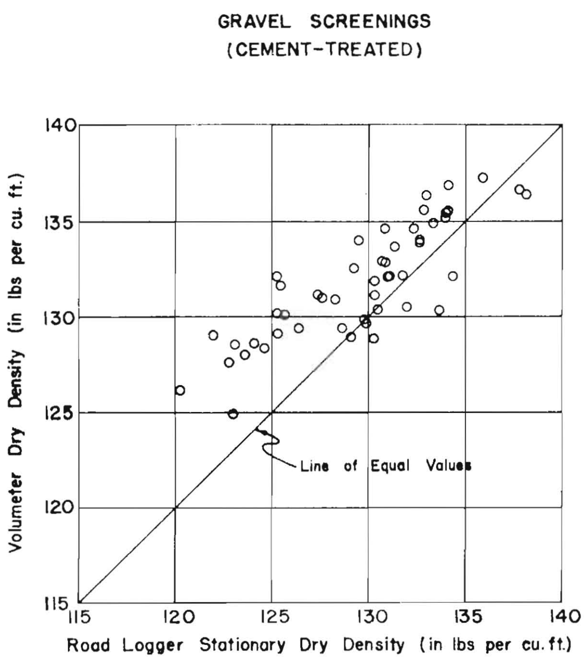
CLAY





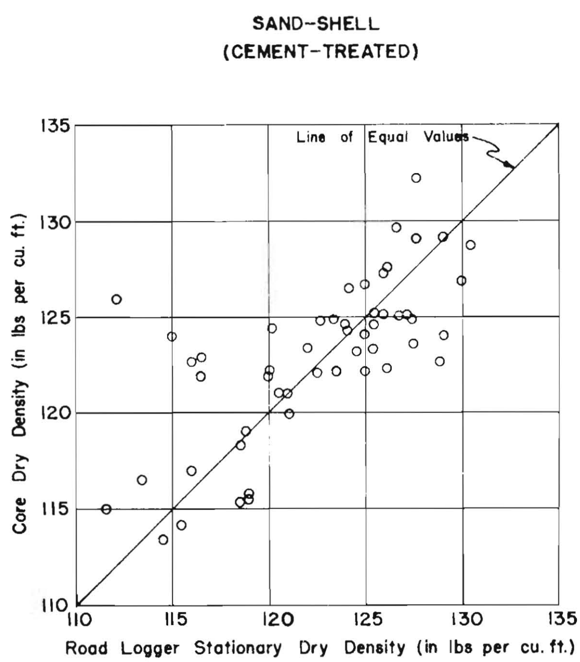
COMPARISON OF ROAD LOGGER STATIONARY Vs. CONVENTIONAL METHODS

FIGURE 7



COMPARISON OF ROAD LOGGER DRY DENSITY Vs. CONVENTIONAL DRY DENSITY

FIGURE 8



COMPARISON OF ROAD LOGGER DRY DENSITY Vs. CONVENTIONAL DRY DENSITY

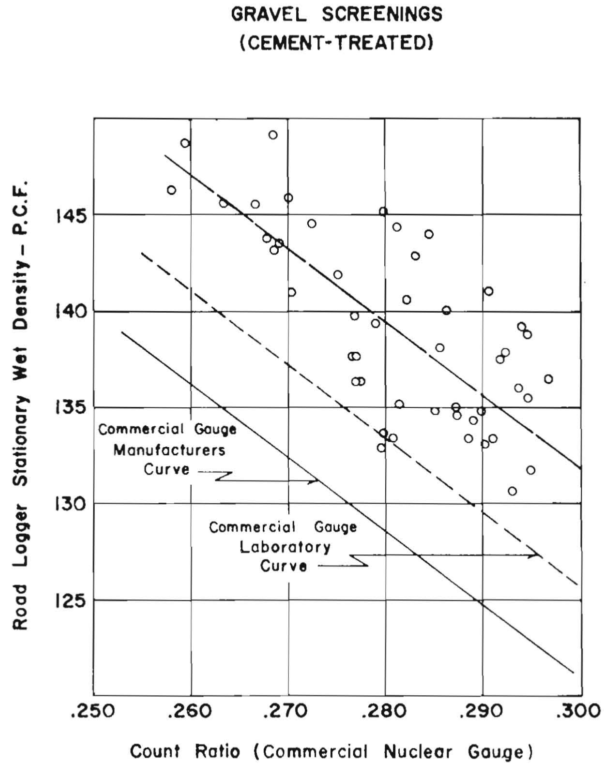
FIGURE 9

Nuclear Gauge Calibration Studies

One of the objectives of the Road Logger study was to determine the feasibility of using this equipment to field calibrate the smaller source, nuclear type surface density gauges. This work consisted of establishing the relationship between surface gauge readings and Road Logger Stationary wet density by taking gauge readings at numerous stationary test sites. Volumeter tests for wet density were also made at many of these same test sites. Figures 10 and 11 illustrate graphically the results of these efforts to develop a field curve for use with one of the surface gauges in testing the cement-treated gravel screenings base material. The line of best fit shown in each figure was drawn by inspection and parallel to the manufacturer's calibration curve. The laboratory curve as shown on the graphs, was determined in the laboratory from surface gauge readings made on laboratory compacted samples. Approximately 70 percent of the wet density values shown in Figure 10 (Road Logger calibration) are within $\pm$ 3 pounds per cubic foot of the line of best fit, whereas approximately 80 percent of the values are within these limits in Figure 11 (Volumeter calibration). Similar efforts made on compacted layers of the sand-shell material resulted in a much wider scattering of points which precluded meaningful establishment of a line of best fit.

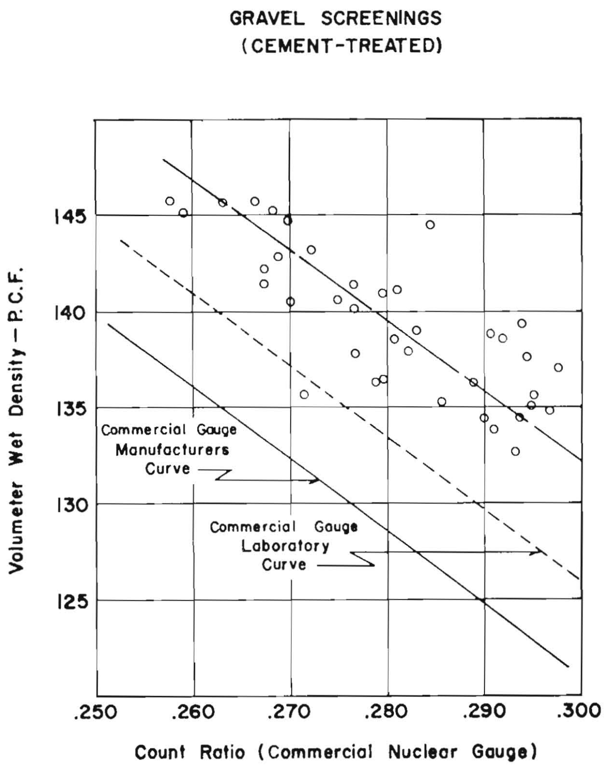
Based on all of the information obtained during the evaluation study, better correlation was obtained using the volumeter test as a standard, rather than the Road Logger, primarily because the volumes measured by the surface gauge and the volumeter are more nearly the same. Variations in wet density, which are present to some extent in all compacted layers, contributed to the observed spread in test results. The calibration curves shown in

Figures 10 and 11 are considered to be fairly typical of the results which can be obtained using this method of calibration for materials of this type. For the sand-shell material, the failure to obtain good curves may be attributed to several factors. Volumeter tests made in a triangular pattern and 1 foot apart, indicated variations in density of as much as 3.5 percent, whereas tests to determine the effects of variations in standoff or airgap between the Road Logger sensing unit and the relatively uneven sand-shell base surfaces indicated that one-quarter inch difference in standoff could result in density variations of 2 percent. These standoff variations could be expected to "average" out during mobile passes, but are known to have had an effect on stationary tests made on the coarse-graded sand-shell bases, and occasionally on some of the finer graded bases.



EXAMPLE OF CALIBRATION CURVE

Figure 10



EXAMPLE OF CALIBRATION CURVE

Figure 11

IV. COMPACTION CONTROL APPLICATION

Project Data and Operational Costs

As mentioned previously, the second period of study was primarily intended to furnish data from which to evaluate the Road Logger as construction control equipment. Because of weather and other factors, work similar to that done during the first evaluation period was also performed during this period in order to obtain maximum benefit from the leased equipment.

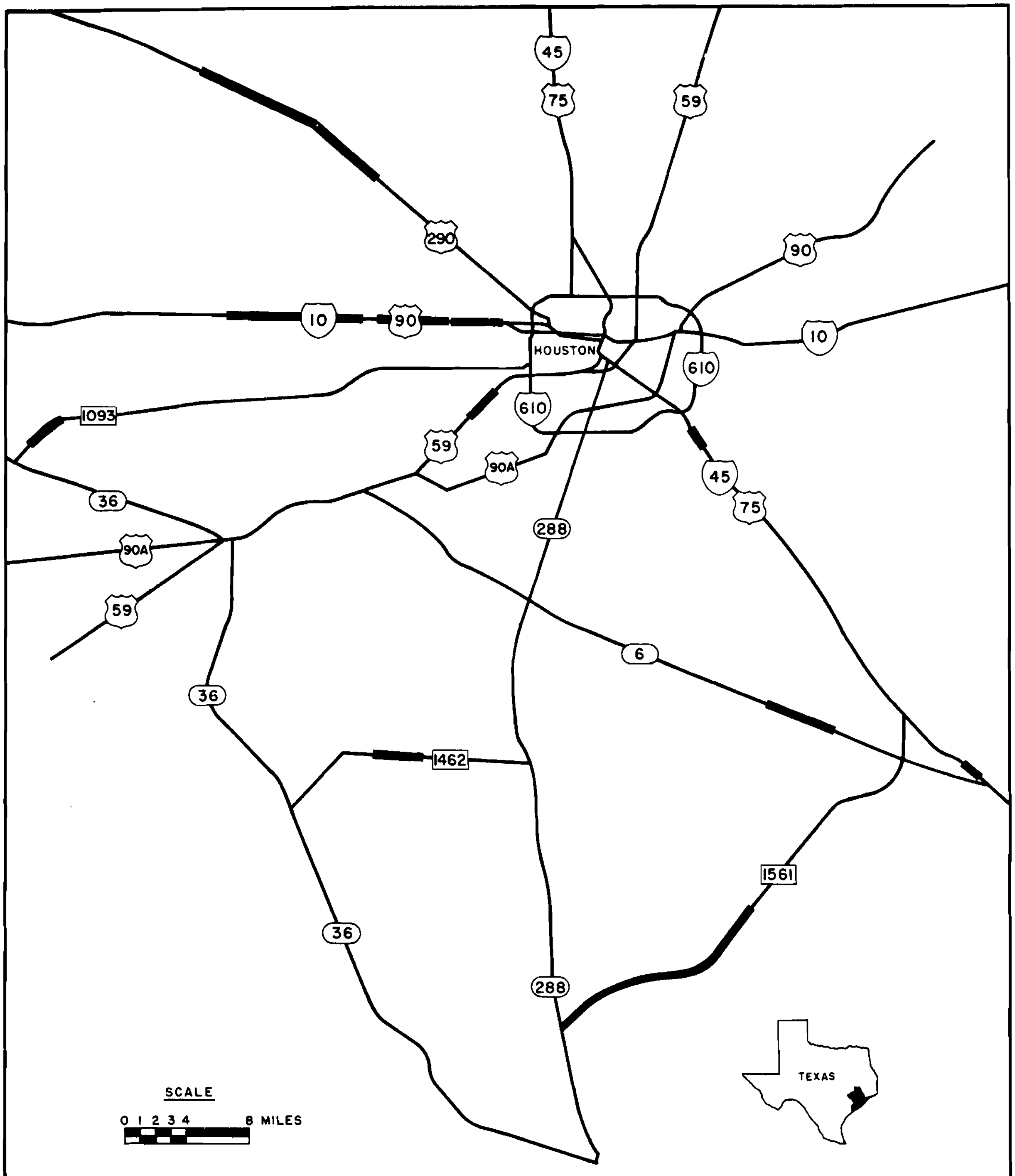
During this second evaluation period, the Road Logger was used on a total of twenty construction projects. On eleven of these projects, the unit was used on a project control basis for judging the adequacy of base course and subgrade compaction operations. The unit was not used to test embankment compaction because of the sensitivity to rough surfaces as determined during the first period of study. Layered embankments, as normally constructed, do not have the smooth surfaces required for testing by this particular model of the Road Logger.

The eleven projects which were selected for evaluating the Road Logger for compaction control purposes were constructed under specifications which included density requirements for base course and subgrade construction. All of these projects were within a 48 mile radius, with the unit operating from a centrally located headquarters.

Even though one trained man can operate the Road Logger successfully, the operating crew for this assignment consisted usually of at least two men to schedule the operations, operate the equipment, and record the required research information. Moisture and density surveys were made on as many as three projects in one day when these projects were close together, and on two projects the same day when the distance separating them was as much as 50 miles. The Road Logger was kept at a central location at night where refueling and other servicing could be readily performed. Decisions relating to operations for the next day were made at the conclusion of work each day. The work schedules were based on anticipated construction operations and the urgency connected with each assignment. Though not extensively used during this particular study, it is believed that the use of radio communications to route the equipment from one project to another would significantly increase the overall efficiency and coverage by a Road Logger unit and therefore add valuable time for measurement operations.

Locations of the projects on which the Road Logger surveys were made for the compaction control study are shown on the map included as a part of this report (See Figure 12). The work was done in an area containing more than the average number of highway construction projects. The area was selected primarily because it would provide for maximum use of the Road Logger under conditions which appeared to be ideal for this type of compaction control operation.

During the entire three months of operation, moisture and density surveys totaling 81.1 miles were completed. Of this total, 35.0 miles or 185,300 feet were logged for the purpose of determining the capabilities of the Road Logger for controlling compaction on construction projects. It had been estimated at the beginning of this phase of work that the Road Logger would be able to complete approximately two miles of moisture and density logging per day within the 48 mile radius of operation. Actual accomplishments during the three month period supported this estimate. It was determined that 1000 feet could be surveyed in a period of 10 minutes allowing for calibration time



LOCATION OF CONSTRUCTION CONTROL PROJECTS

Figure 12

and for other preliminary duties necessary in the logging operation.

During the three month period, the Road Logger did not work on 7 of 59 possible working days due to minor malfunctions or breakdowns. In addition to the days lost for minor repairs, 10 days were lost due to unsatisfactory weather and/or working conditions on the projects. The fact that no work was available for the Road Logger on some days caused additional losses in working time.

Operating cost figures, as determined from total expenses during the evaluation period, indicate that the 81.1 miles were surveyed at a unit cost of $2.10 per 100 feet. This unit cost is based on Road Logger commercial rental rates of $833.33 per month and $45.00 per mile of survey, plus actual operating costs consisting of operator wages, equipment servicing costs, and warehouse supplies needed in the work. The unit cost per 100 feet for doing the 35 miles of compaction control testing on the 11 projects within the 48 mile radius of operation was computed to be $2.05. It is considered coincidental that the two unit costs, for all practical purposes, were the same. This agreement in unit costs would indicate that the time necessary to travel longer distances to the projects outside the 48 mile radius was offset by the delays incurred on the compaction control projects due to the sequence of contractor operations.

Special Studies and Investigations

The Road Logger and the mobile logs of moisture content and density were the basis for making several special studies and investigations.

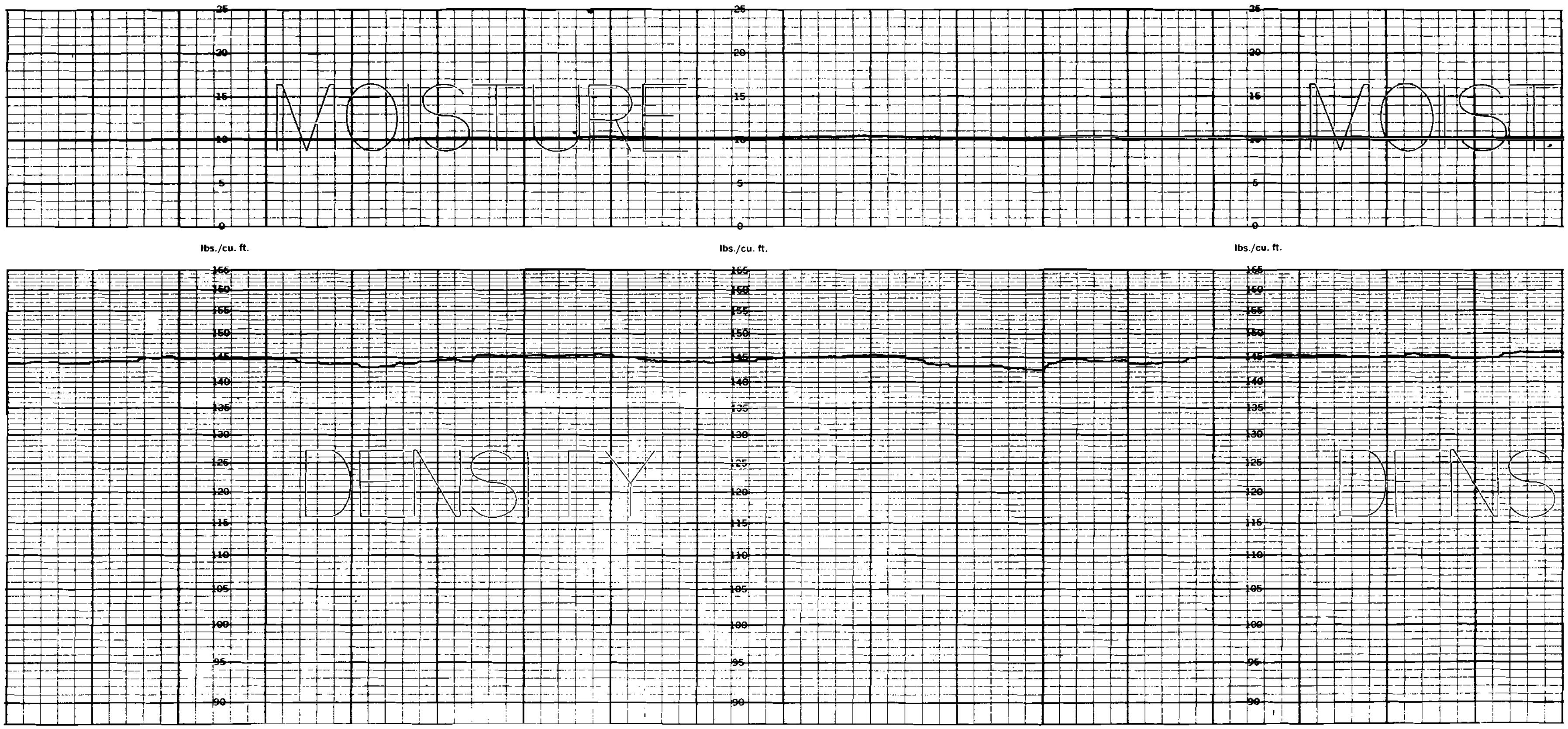
1. A study was made of Road Logger capabilities to duplicate measurements of moisture content and wet density. This work consisted of making separate logs of moisture content and density by repeating

passes over the same strip of roadway. Three such logs were made and a composite of the logs indicated maximum deviations in moisture content and wet density of approximately one pound per cubic foot.

2. The Road Logger was used to determine the limits of areas needing additional investigation as indicated by conventional tests, such as areas of low density, thin pavements, changes in material, etc.
3. The Road Logger was used to check the uniformity of moisture content in the compacted layers and its effect on meeting specification compaction requirements.
4. Isolated studies were made to determine the effectiveness of various types of rollers, including the effects of the number of passes and changes in weight for a particular roller.
5. The mobile logs provided by the Road Logger were used to check the compaction at the construction joints in cement-treated layers, and to investigate the effectiveness of new methods for obtaining better compaction at these joints.
6. The mobile logs provided a means of studying variations in density which can be expected in uniformly compacted base and subgrade soil materials. Figures 13 through 16 are examples of mobile logs obtained from moisture and density surveys made of gravel screenings, sand-shell, and burned clay base courses and lime-treated subgrade soil. These examples represent sections 900 feet in length and indicate, to some extent, the variations in density which can be expected in compacted layers of materials similar to those surveyed during this evaluation study. Figure 17 illustrates the density

variation as indicated by the Road Logger in a crushed limestone section, also 900 feet in length, and located in an adjoining highway district.

GRAVEL SCREENINGS
(CEMENT-TREATED)
6-inch Thickness



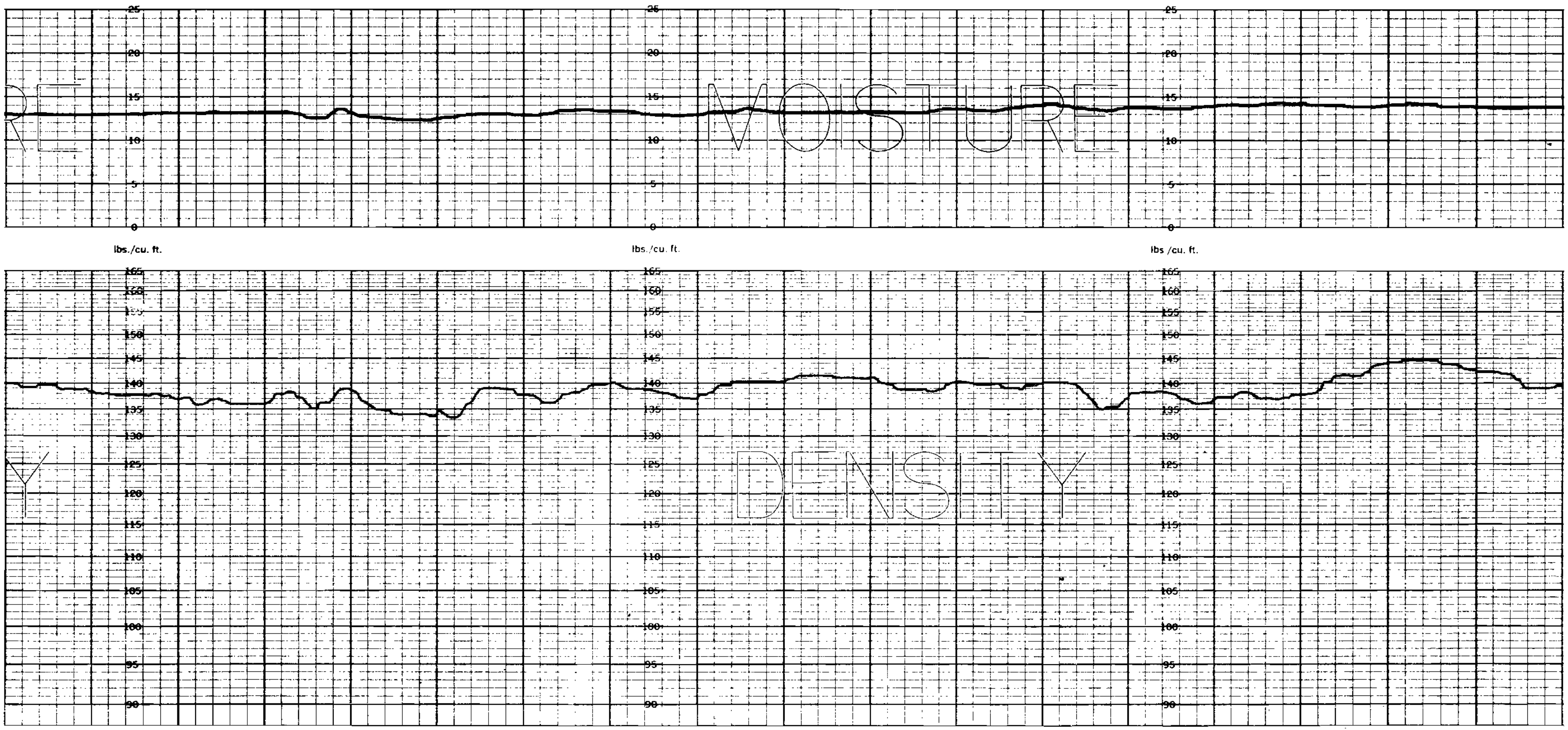
MOBILE LOG FOR GRAVEL SCREENINGS BASE COURSE

FIGURE 13

SAND-SHELL

(CEMENT-TREATED)

6-inch Thickness



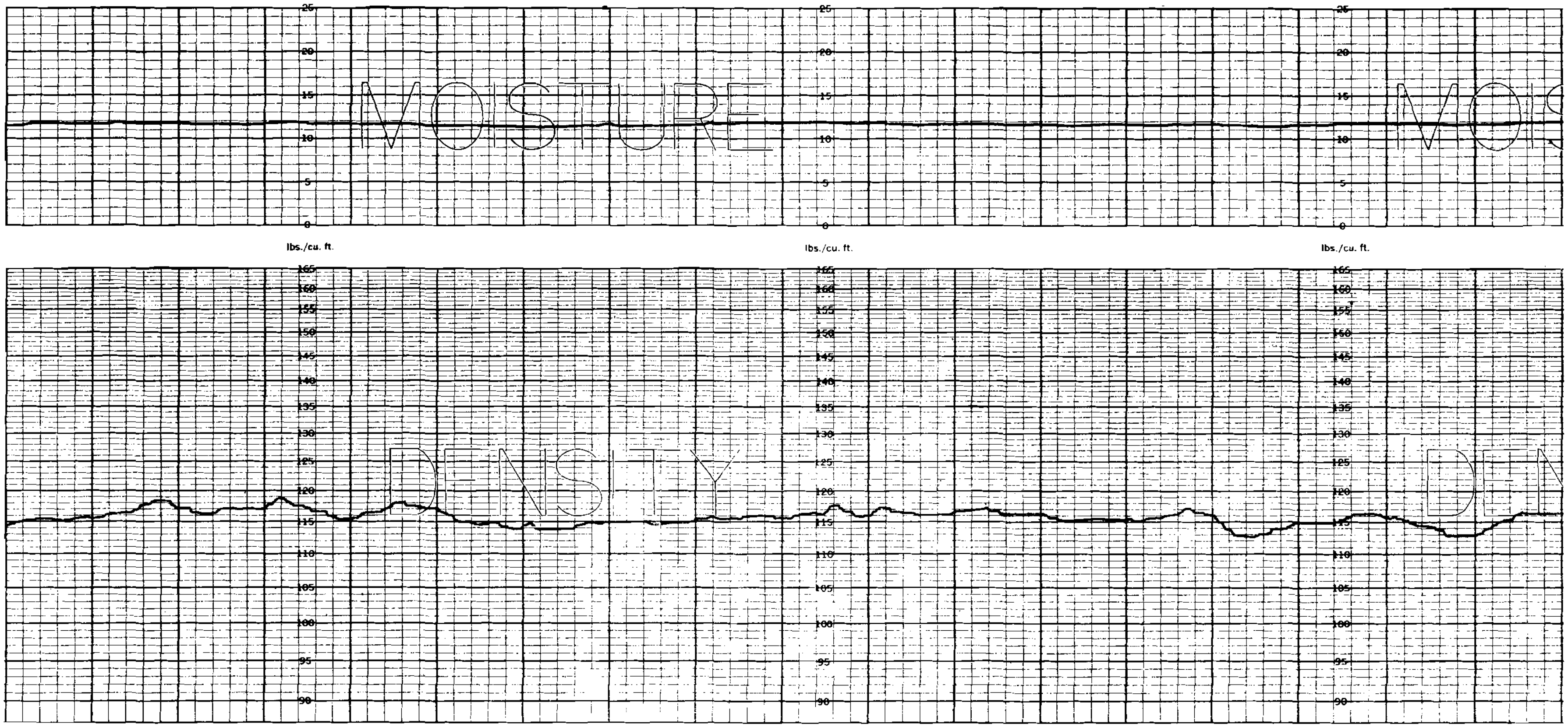
MOBILE LOG FOR SAND-SHELL BASE COURSE

FIGURE 14

BURNED CLAY

(CEMENT-TREATED)

6-inch Thickness



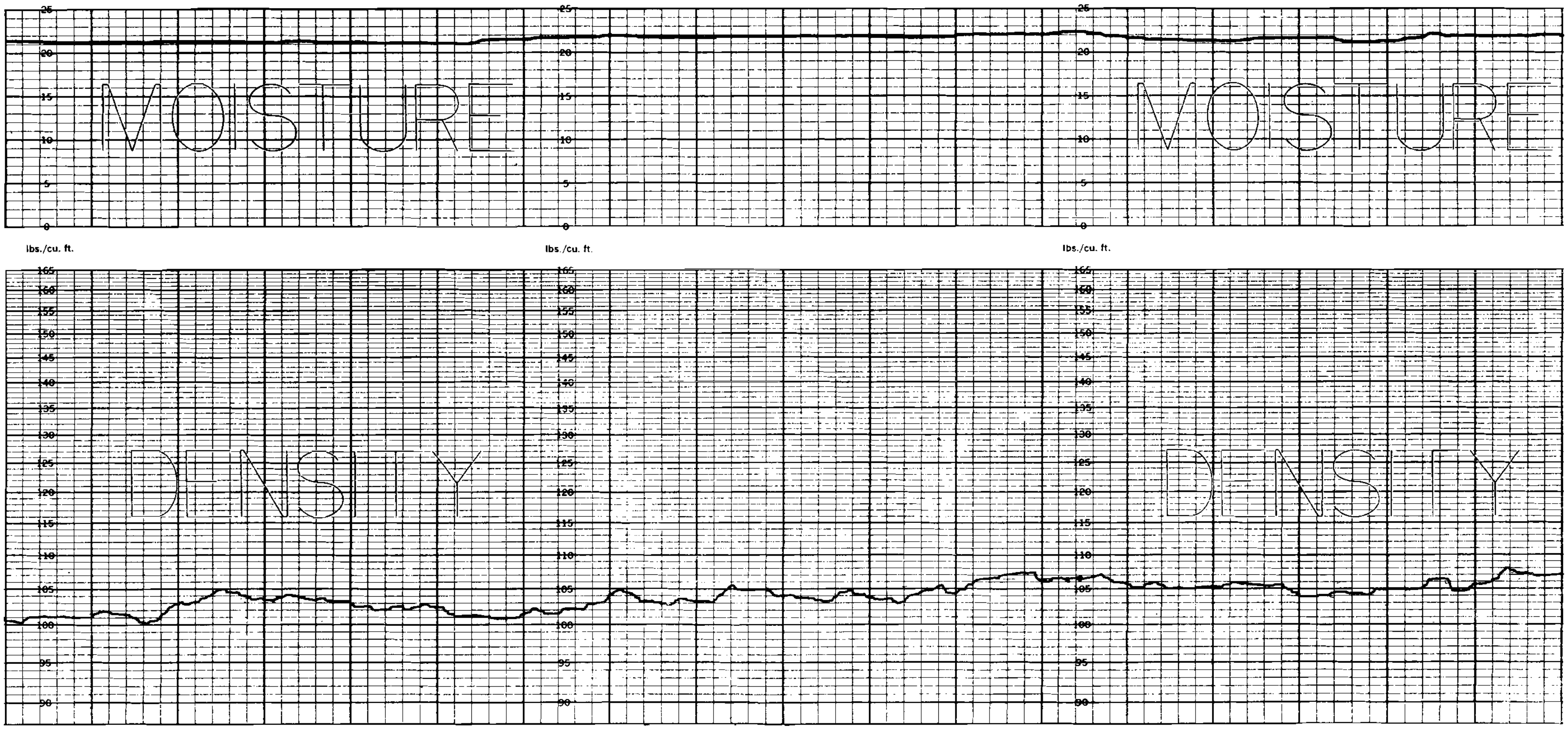
MOBILE LOG FOR BURNED CLAY BASE COURSE

FIGURE 15

CLAY

(LIME-TREATED)

6-inch Thickness

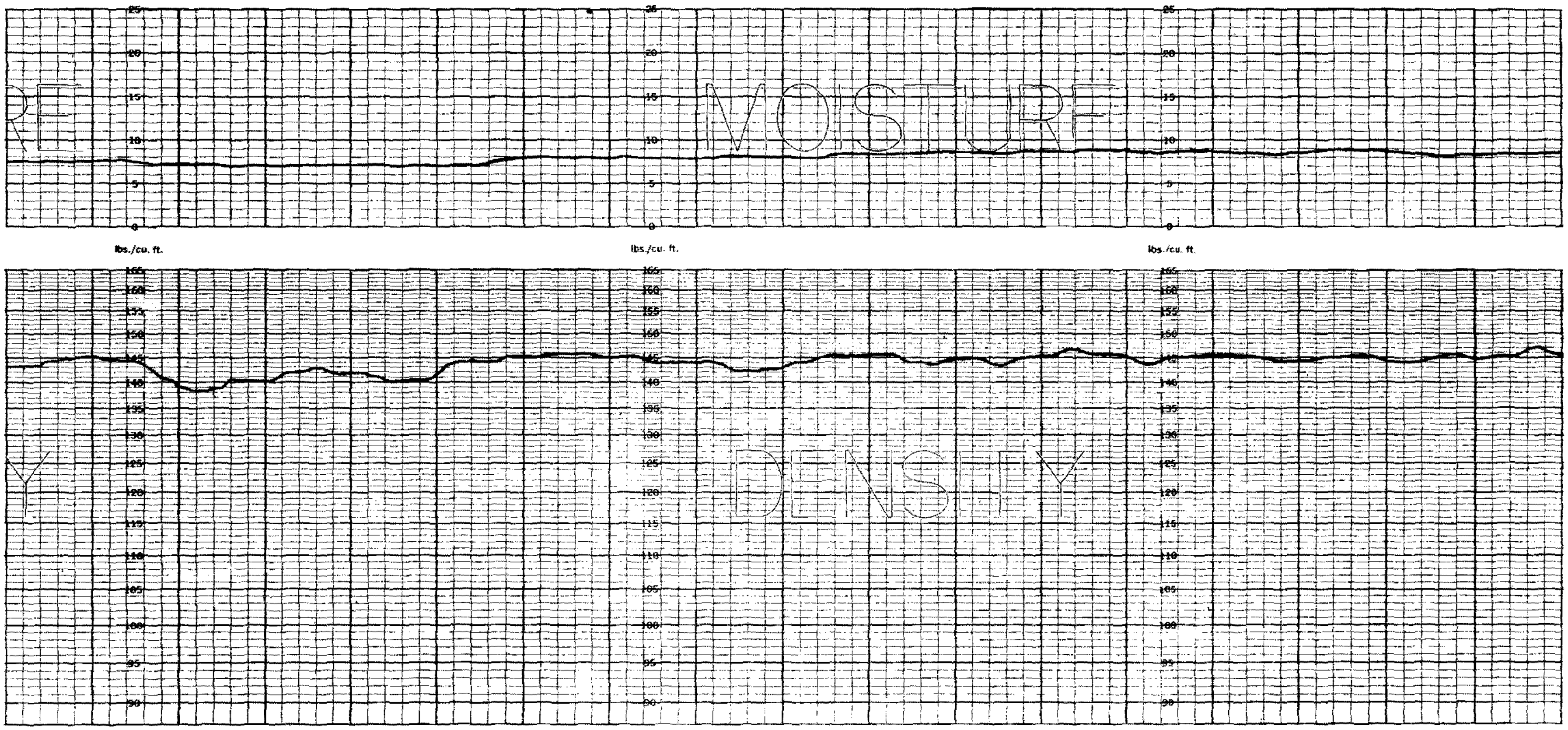


MOBILE LOG FOR CLAY SUBGRADE

FIGURE 16

CRUSHED LIMESTONE

8-inch Thickness



MOBILE LOG FOR CRUSHED LIMESTONE BASE COURSE

FIGURE 17

VI. FINDINGS

On the basis of the results of the Road Logger evaluation studies that are described in this report, the following findings are considered to be significant:

1. The Road Logger measurements of moisture content and density in uniform base courses and subgrade layers correlate with those of the standard oven-dry and volumeter test methods.
2. In most of the materials that were tested during this research study, the Road Logger moisture content exceeded that of the standard test by 2 to 3 pounds per cubic foot. Theoretical concepts indicate that these higher moisture values were due to neutron penetration into relatively moist underlying layers and to nuclear detection of "bound-up" moisture (hydrogen) that was not measured by the standard test.
3. Road Logger measurements of wet density generally exceeded those obtained by the volumeter test by 1 to 5 pounds per cubic foot. The higher Road Logger values appear to be due mostly to the differences in the principles of measurement involved and to variations in density in the test layers.
4. The Road Logger models used in this research study were sensitive to uneven surface characteristics and for this reason were not used to measure moisture content and density in embankment construction. The unit used during the second study proved to be very mobile and maneuverable and was used effectively for checking the compaction of base courses and finished subgrade layers.

5. The Road Logger proved to be effective in investigating construction procedures and in investigating areas of low density, non-uniform moisture content, etc.

6. The mobile logs provided by the Road Logger indicated that significant variations in density existed in all of the compacted layers that were tested. These findings support the belief that such factors as material change, varying support from foundation soils, inability to secure perfect distribution of moisture and compactive effort, and others make it desirable that there be some flexibility in compaction specification requirements.