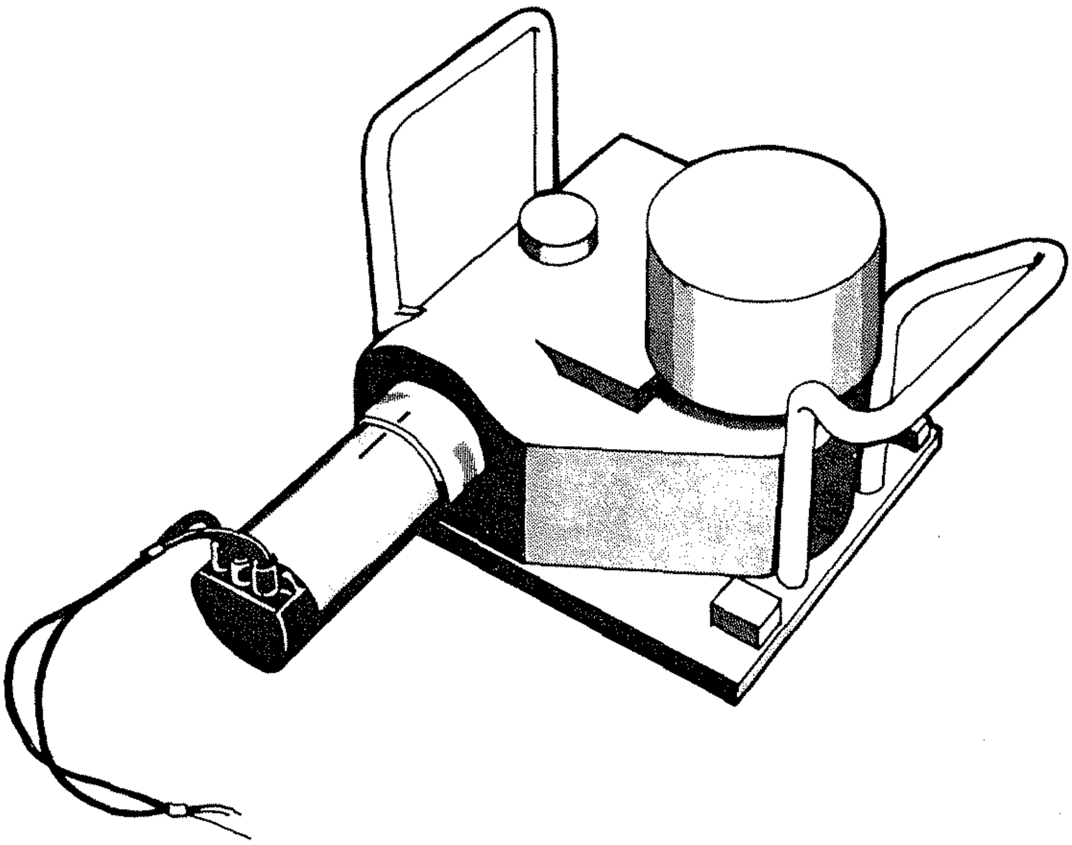
An Evaluation Of The

Second Generation Consolidation Monitoring Device

Final Report
Project HR-1013



January 1984
Highway Division

Iowa Department of Transportation

An Evaluation of the Second Generation Consolidation Monitoring Device

FINAL REPORT
FOR
Iowa Department of Transportation
Research Project HR-1013

CONDUCTED FOR THE
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Federal Highway Administration

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TASK ORDER NO. 14

BY

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INTRODUCTION

The Consolidation Monitoring Device (CMD) was developed for the Federal Highway Administration (FHWA) to continuously monitor the density of plastic portland cement concrete immediately following placement by a paving machine. The device is attached to the rear of a paving machine.

As the strength, chemical resistance, and life of PC concrete are affected by the density, it would be very beneficial to know the density of the plastic concrete. If the concrete ~~were out~~ of ~~specification~~, correction of the problem would be more economical while the concrete was in the plastic state. LOW DENSITY - WAS ENCOUNTERED

The prototype CMD was field tested in Iowa in 1978. It was concluded that the impossible task of maintaining the necessary one-inch air gap was the probable cause for the poor field correlation with core densities.

To overcome the air gap problem, a method to electronically compensate the density reading for air gap variation was developed and added to the system. The second generation CMD was ready for field testing and in July of 1983, Iowa was again selected as a test site.

OBJECTIVE

The objective was to evaluate the usefulness, accuracy, precision, and reproducibility of the second generation CMD for PC concrete under production conditions.

SYSTEM DESCRIPTION

The second generation CMD was developed for the FHWA by Foster-Miller, Inc. of Waltham, Massachusetts. The system consists of a control and readout unit; a radioactive source and a photomultiplier (PMD) tube which are placed in a lead shield carrier (source-sensor unit); a flat capacitance distance transducer; traversing mechanism; and associated cables.

The control and readout unit contains the circuitry, battery, controls, and meters for operating the CMD. A chart recorder is also enclosed in the same case (Fig. 1).

A hinged guide beam is mounted on the rear of the paver. The hinged mounting allows the beam to follow the cross-section of the pavement. The source-sensor unit containing the radioactive source, PMD tube and the flat capacitance distance transducer are placed in a motor driven carriage. The carriage can traverse at variable speeds or be held in a stationary position on the guide beam.

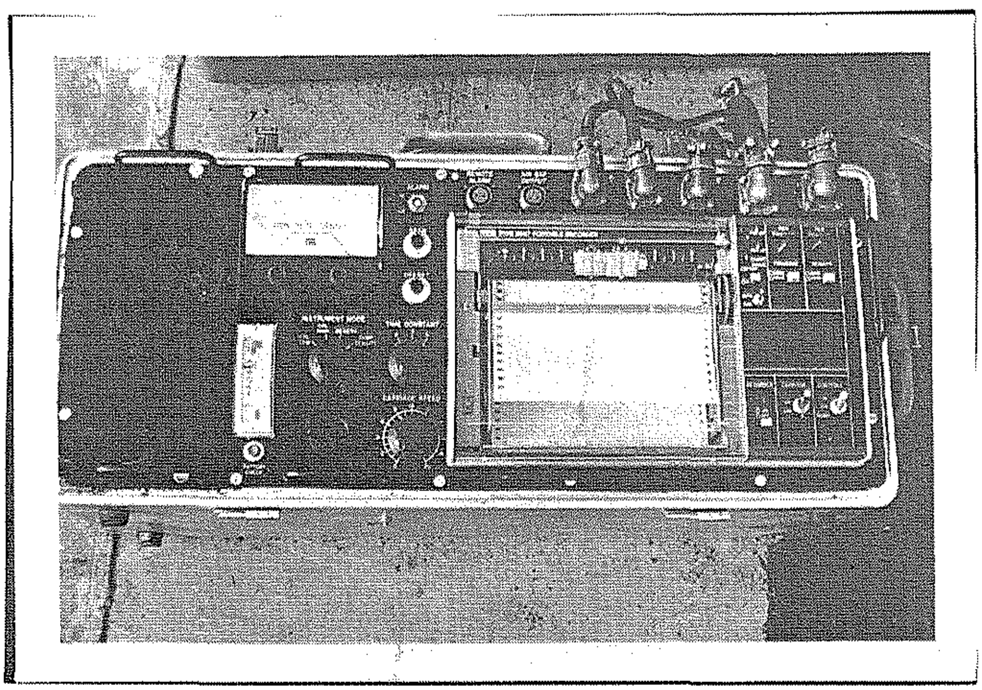


Fig. 1 - Control & Readout Unit

Gamma rays from the Cesium 137 radioactive source are emitted downward into the concrete (Fig 2). The number of gamma rays reflected and detected by the PMD tube are dependent upon the density of the concrete. The result is converted to density and read as lbs/cu ft on a meter and recorded on the strip chart.

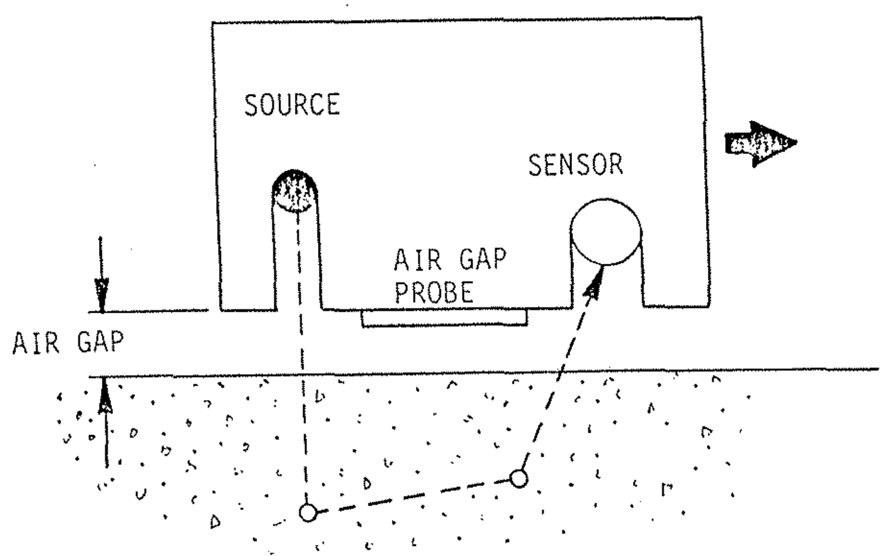


Fig. 2 - Typical Gamma Ray Path

The air gap between the source-sensor unit and the pavement surface was a critical factor on the first generation CMD. An air gap probe on the second generation CMD measures the air gap by means of changes in capacitance between the probe and concrete surface. The density reading is compensated to a one-inch air gap. The compensated air gap range is one inch ± 0.4 inch. If the air gap leaves this range, the recorded density will not be correct.

Laboratory Evaluation

The laboratory testing consisted of:

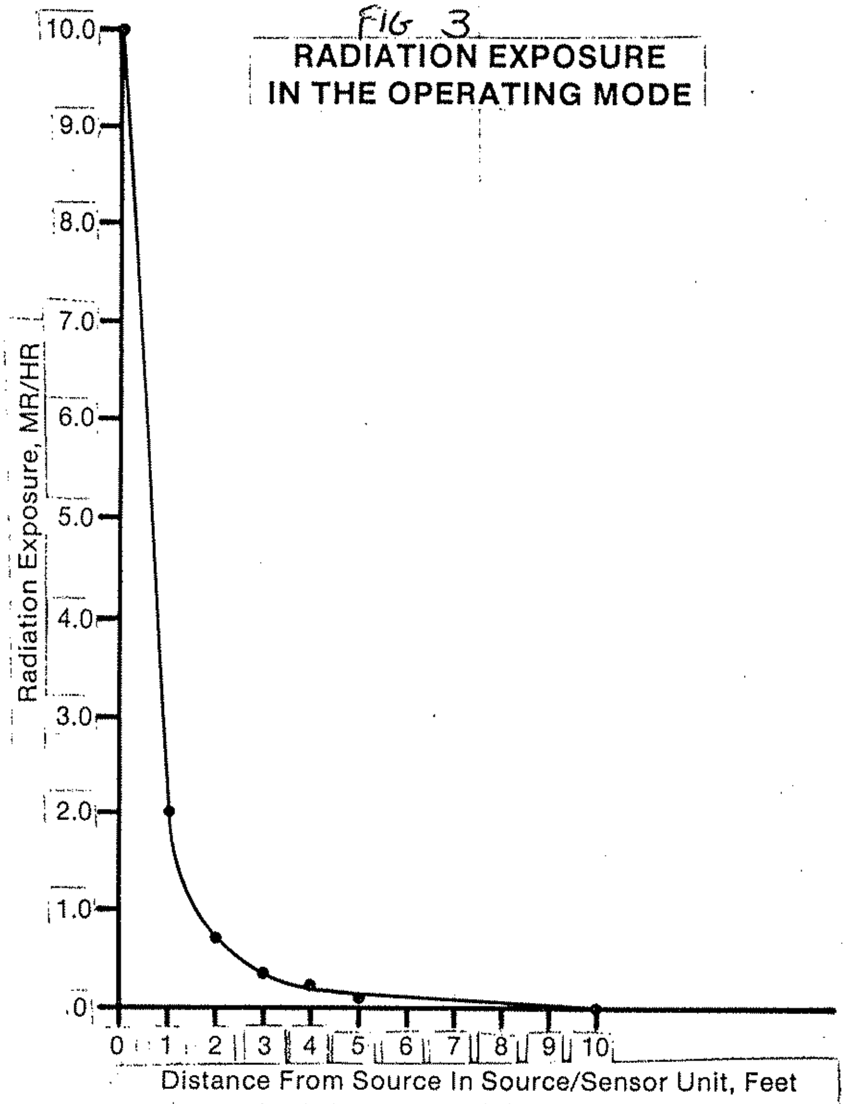
1. Determining the radiation emission from the radioactive source in the source-sensor unit.
2. Calibrating the CMD according to the instruction manual (APPENDIX A).
3. Comparing the CMD with a commercial nuclear gauge.
4. Determining the depth of influence of the CMD.
5. Determining the area of influence of the CMD (edge effects).
6. Determining the effects of changes in air gap without the air gap probe.
7. Determining the effects of varying the time constant.

Radiation Exposure

Radiation exposure is the first concern when operating radioactive devices. To determine radiation exposure, the source-sensor unit was placed on the calibration block in the operating mode and measurements were made at six different distances (Fig. 3). AT Two feet from the source-sensor unit the radiation exposure is 0.7 mr/hr and at three feet the radiation exposure is 0.5 mr/hr.

Personnel working with the CMD were required to wear film badges to monitor radiation exposure. The film badges of two people that were associated with the CMD part time showed zero radiation exposure. The person involved full time with the CMD received a total of 60 millirem during a two-month period (Appendix B).

FIG 3



The exposure limit for radiation workers for sensitive regions (whole body, gonads, eyes, skull) is 96 millirem per week. Some typical radiation exposures are:[2]

chest x-ray	100 millirem
tooth x-ray	10-30 millirem
jet flight NY-SF	3 millirem
background in Iowa (avg.)	0.33 millirem/day

A leak test was performed before evaluation and prior to shipment to Texas. No leakage was measured in either test indicating the CMD is safe when properly used.

2 Instructional Manual MC-1 Simultest Compaction Gauge, Campbell Pacific Nuclear Cor., Pachico, CA, 11/76, pp 3, pink section.

Laboratory Calibration

The laboratory calibration consisted of three steps. The first step was to calibrate the CMD on fresh concrete samples using the same aggregates and mix (Appendix C) as used in the paving project. This was to negate the effects of aggregate composition on the CMD readings. Densities were measured with the CMD (Fig. 4) and a Campbell Pacific nuclear gauge (Fig. 5). Three concrete samples (high density-low air, normal, and low density-high air) were prepared to calibrate the CMD. The calculated densities were 154.1 lbs./cu.ft. for the high density mix, 143.7 lbs./cu.ft. for the normal mix, and 137.0 lbs./cu.ft. for the low density mix. The CMD was adjusted to correspond with the above calculated densities. The range was sufficient to cover densities of concrete placed during field testing.

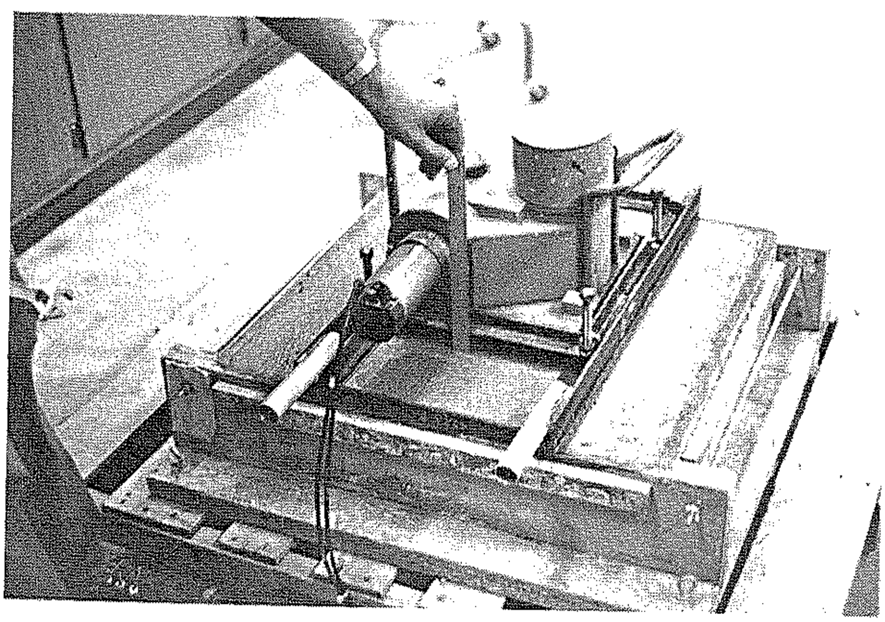


Fig. 4 - Laboratory Calibration of the CMD

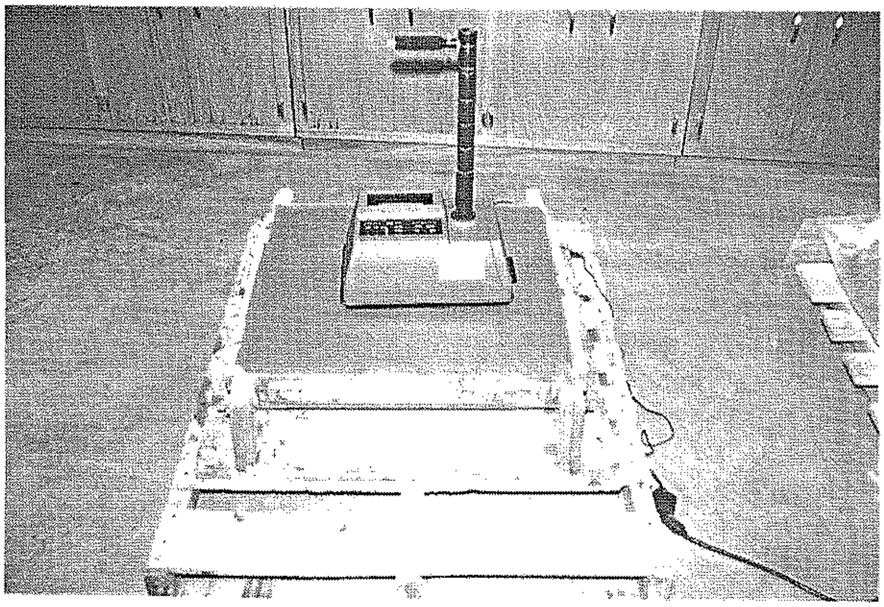


Fig. 5 - Laboratory Correlation with a
Campbell Pacific Nuclear Gauge

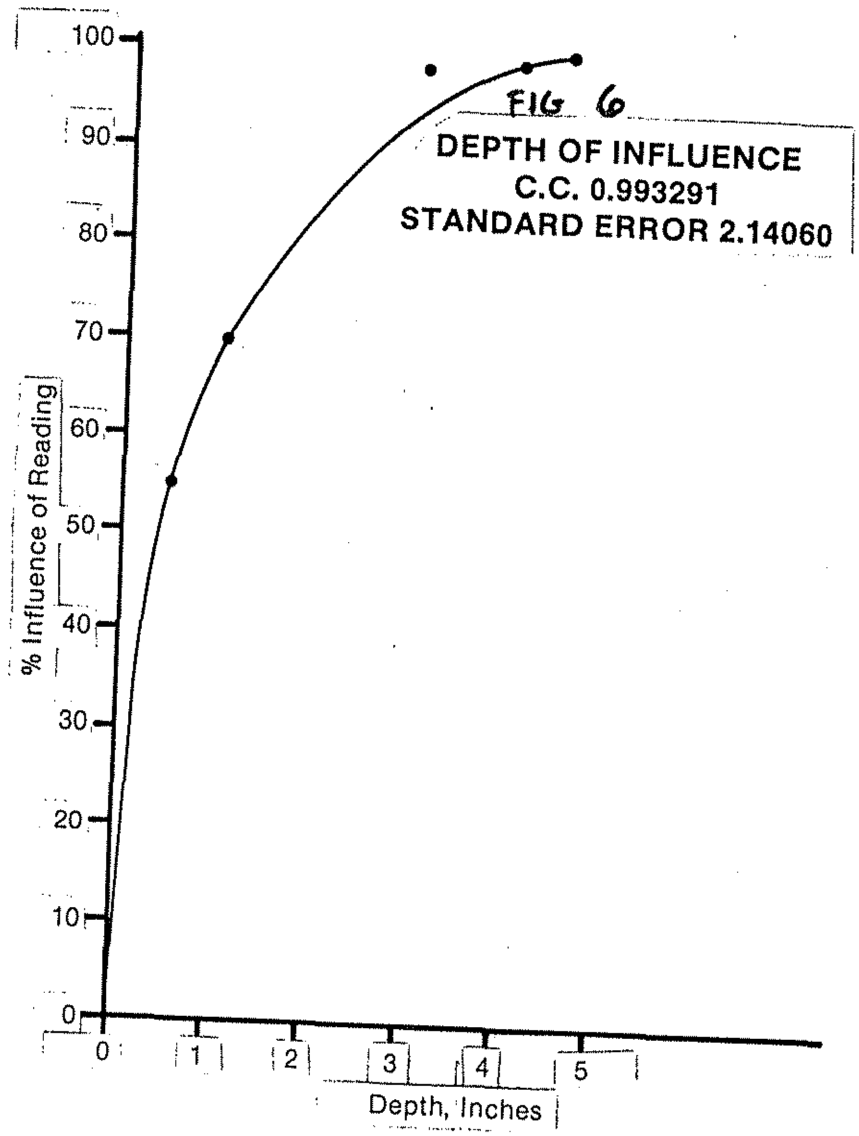
The second step involved the magnesium-aluminum calibration block. Immediately after calibration on fresh concrete, the source-sensor unit was placed on the calibration block and 136 lbs/cu ft were indicated. A steel insert was then placed on the calibration block giving a second density reading of 161 lbs/cu ft.

The calibration block readings are recorded for field calibration. Each morning before field testing the CMD was placed on the calibration block and adjusted, if needed, to the above values. This was to eliminate day-to-day drift in the electronics.

The last step is to correct any electronic drift during testing. A function switch that has the positions of cal high and cal low allows the testing personnel to check the electronics for variations while on the paver. In the "cal" positions a density signal is simulated within the control and readout unit. This ~~does not~~ TEST checks the ~~entire circuit~~ ELECTRICAL CIRCUITRY WITHIN THE CONTROL & READOUT UNIT. After calibration on the calibration block, the function switch is turned to cal high and cal low and the density readings recorded, in this case 159 lbs/cu ft and 137 lbs/cu ft were indicated respectively. During field testing if cal high or cal low are outside the designated reading by more than 2.0 lbs/cu ft, the CMD should be adjusted to the original calibration values. After calibration, very little adjustment was needed.

Depth of Influence

The CMD, being a radiation backscatter device, has limitations to the depth of ~~its readings~~ INFLUENCE. To determine this depth, various thicknesses of concrete having a density of 148 lbs/cu ft were placed over a steel plate having a density of 484 lbs/cu ft and the density readings recorded. Density on concrete of thicknesses less than 2-1/2" could not be recorded as the readings were off the scale. To obtain more data, 1/2" and 1" thick pieces of neoprene, density of 79.2 lbs/cu ft and 83.5 lbs/cu ft respectively, were placed over a standard granite block, density of 165.5 lbs/cu ft, and the density readings recorded. A depth of influence graph was developed (Fig. 6). The surface of the concrete has the greatest influence over the density reading and the influence decreases rapidly with depth. Seventy percent of the density reading is ~~determined by~~ FROM the top 1" of concrete and 85% ~~by~~ FROM the top 2".



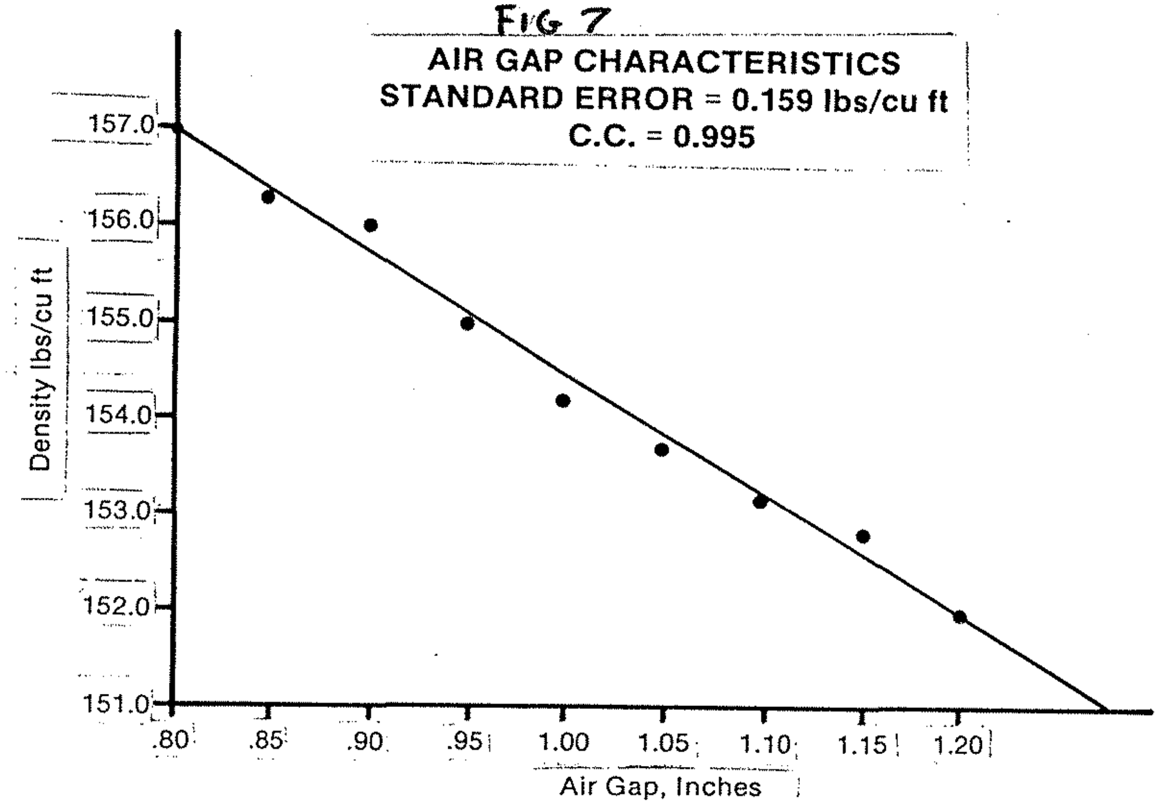
Areas of Influence (Edge Effects)

All nuclear gauges become innacurate as the area of influence intercepts a vertical edge. A test conducted on a fresh concrete sample determined that 7" from the source to the edge are required to eliminate the edge effect. During field testing, the CMD could not traverse closer than six feet to the pavement edge because a paver brace limited the carriage traverse.

Air Gap Characteristics

The major problem of the first generation CMD was keeping a constant 1" ± 1/16" air gap. If the air gap deviated from this range, the density reading was dramatically affected. The second generation CMD air gap characteristics were investigated. Varying the air gap 0.05" will change the non-compensated density reading 0.62 lbs./cu.ft. (Fig. 7). With the air gap compensation of the second generation CMD, very few adjustments were necessary to maintain the required air gap during field testing.

FIG 7



Time Constant Characteristics

A time constant switch on the control and readout unit having three positions -- 2, 3, and 5 seconds, averages the density signal over the designated time. The constant has a direct relationship to the density trace recorded on the strip chart. A longer time constant evaluates a larger area of pavement tending to give a smoother trace. The time constant for field testing was five seconds. The density trace of the second generation CMD has greater (INHERIT) variations than the first generation CMD when comparing both at the same time constant setting. The characteristics for the different time constants are shown below (FIG 8-12).

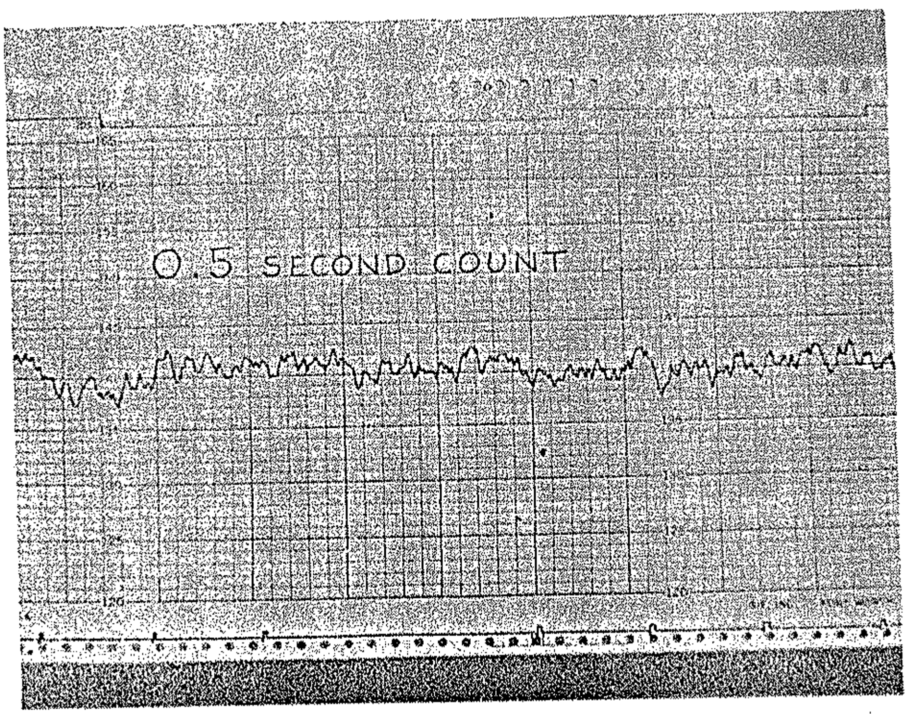


FIG 8

~~Trace during 0.5 second setting~~, ~~OF~~
~~FIRST GENERATION CMD~~

DENSITY TRACE OF THE FIRST GENERATION
CMD AT ~~THE~~ 0.5 ~~11~~ SECOND SETTING

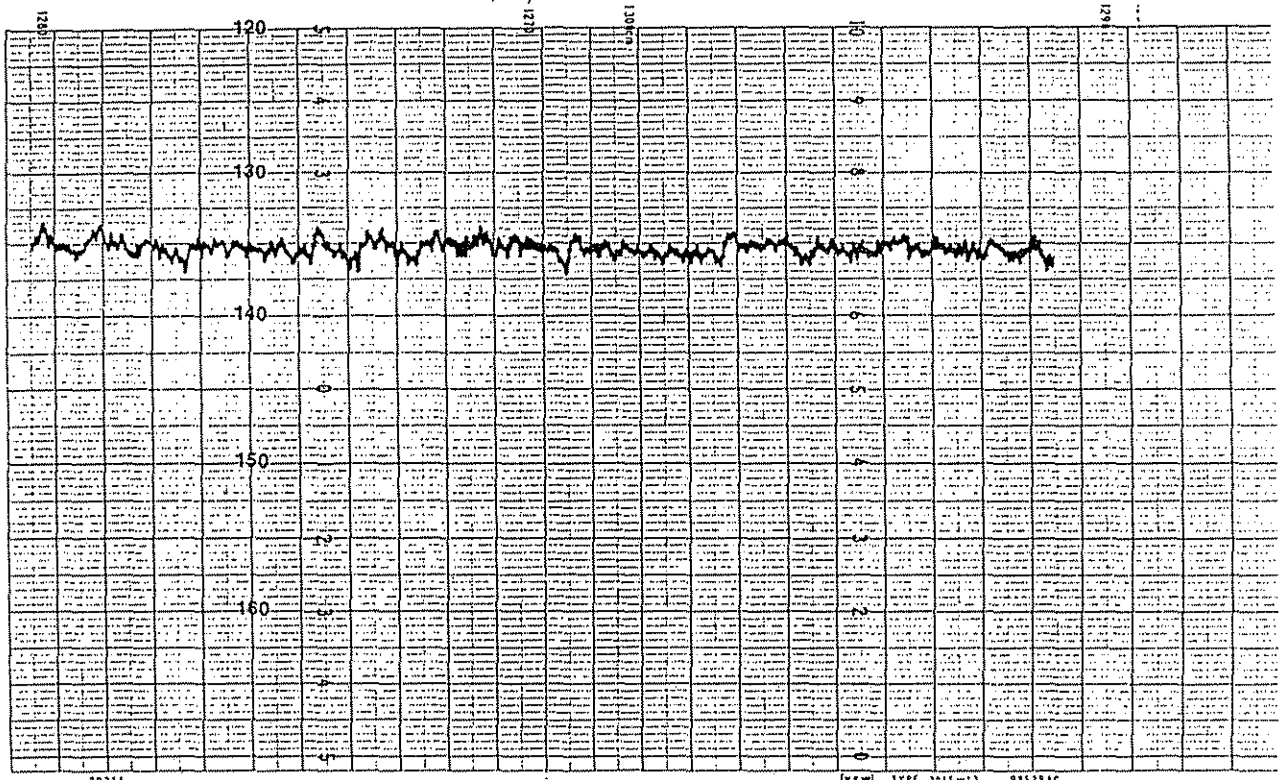
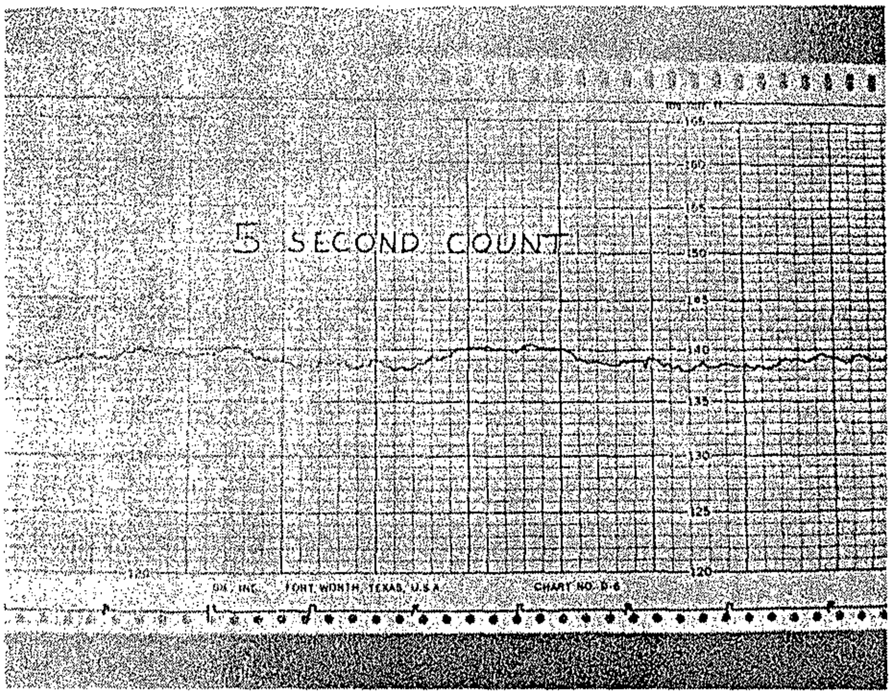


FIG 9

DENSITY TRACE OF THE SECOND GENERATION CMD AT THE 5 SECOND SETTING



~~Photo~~ FIG 10

DENSITY TRACE OF THE FIRST GENERATION CMD AT THE 5 SECOND SETTING

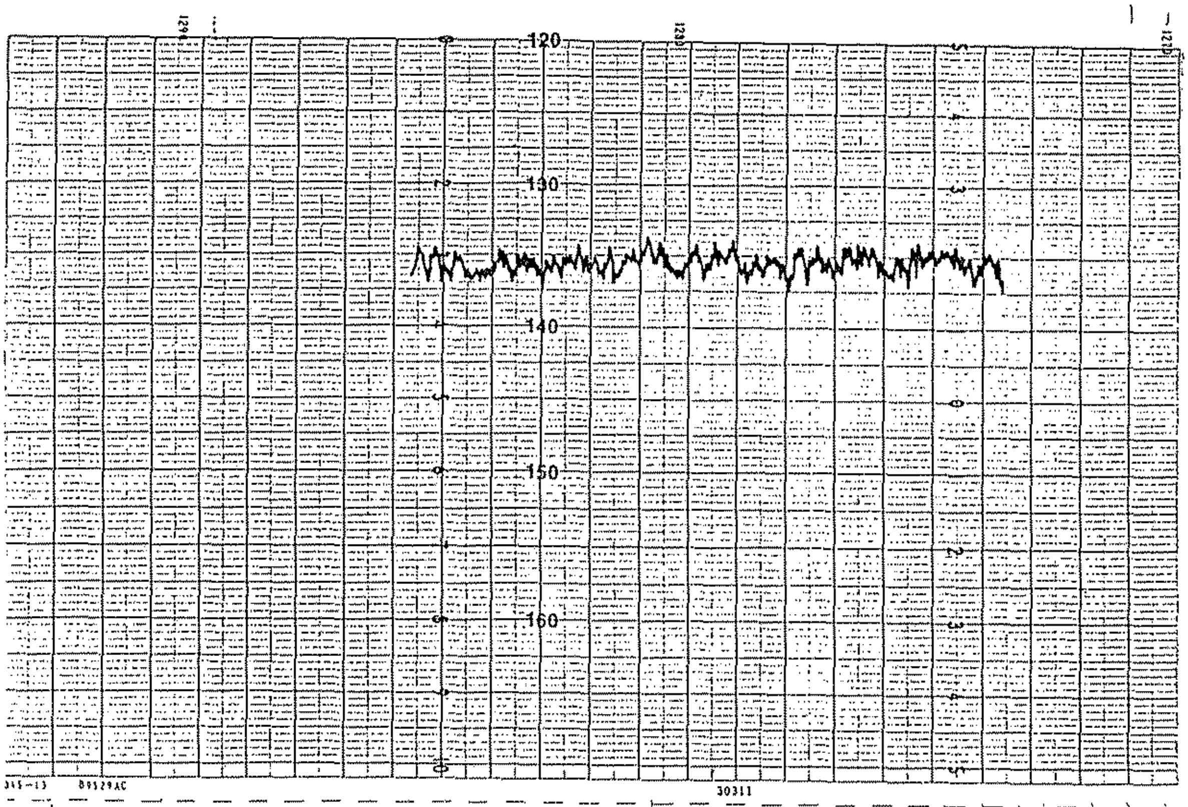


FIG 11

DENSITY TRACE OF THE SECOND GENERATION
CMD AT THE SECOND SET

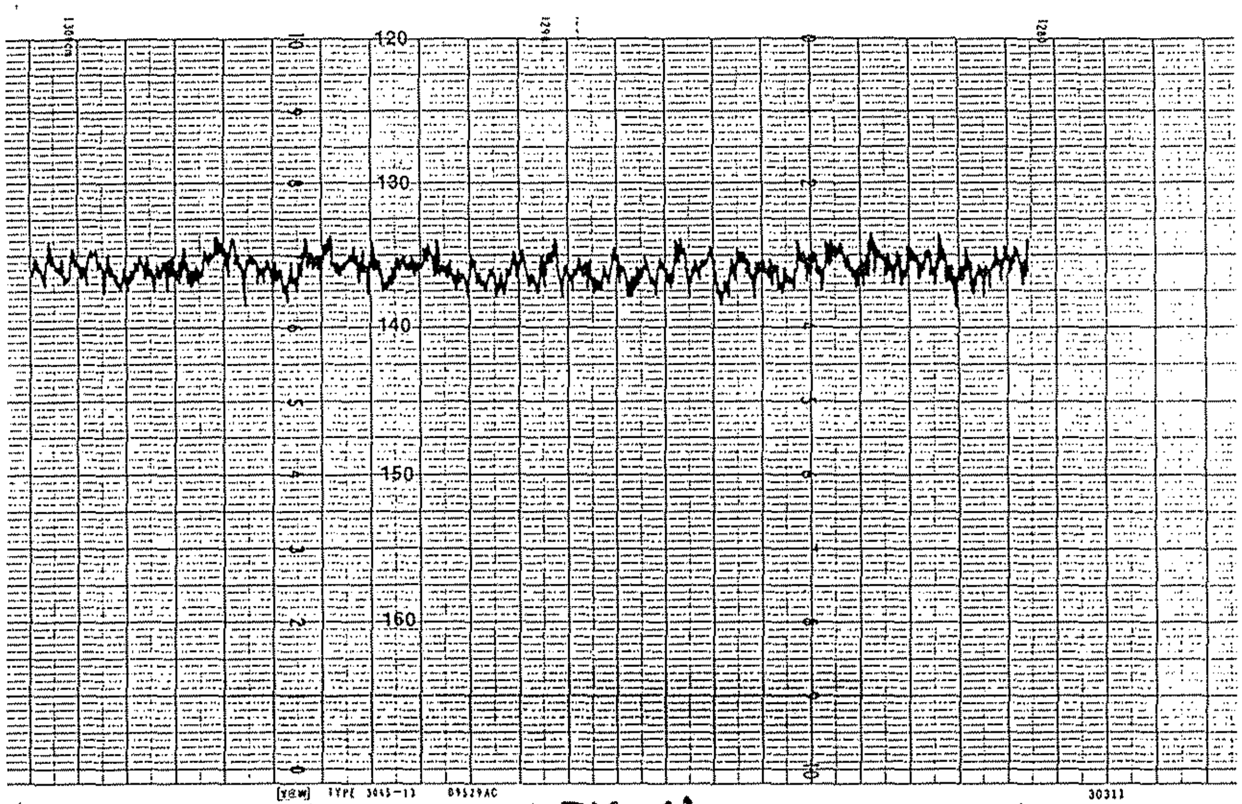


FIG 12

DENSITY TRACE OF THE SECOND GENERATION
CMD AT THE SECOND SETTING

Field Evaluation

The field evaluation was conducted during the paving of Iowa 330 from U.S. 65 to U.S. 30 in Jasper and Marshall counties in September of 1983. The contractor, Fred Carlson, Inc. of Decorah, Iowa, used an STR REX slip form paver on which the CMD was mounted (Fig. 13).

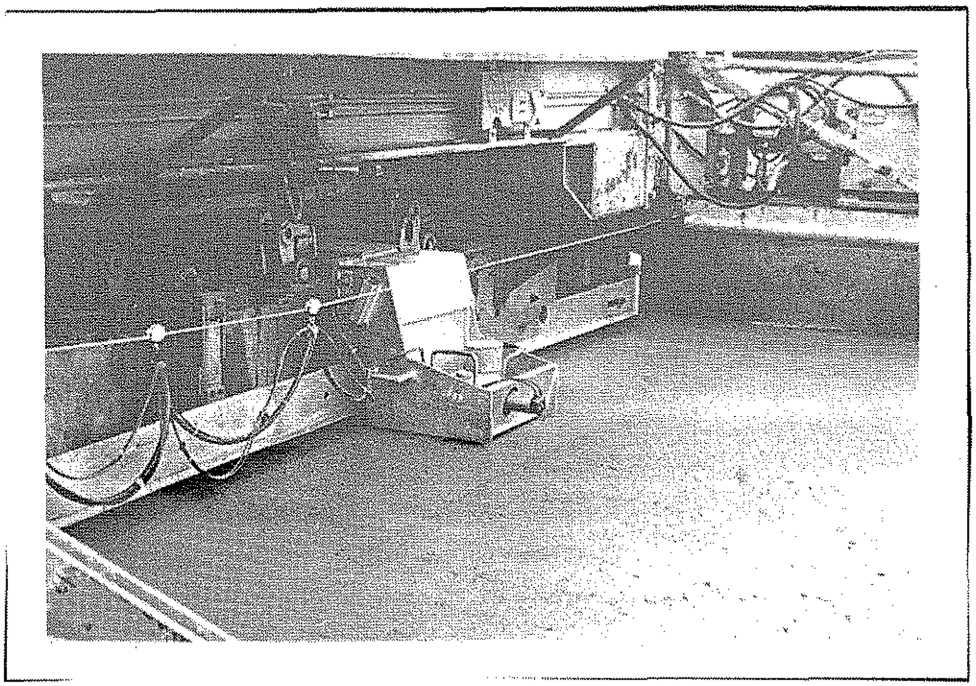


Fig. 13 - Field Evaluation of the CMD

The hinged guide beam as received was 25 feet long, making it impossible to mount between the 24-foot wide forms of the REX paver. It was necessary to cut 1-1/2 feet from each end of the beam and drill new holes for the magnetic direction change system. This was accomplished in the Iowa DOT Materials machine shop. It was also necessary to weld channel iron sections to the top of the extrusion meter on the paver to support the guide beam at the required elevation.

Because of the size of the source-sensor carriage, the CMD could not traverse past the extrusion meter supports; therefore, only the middle 11-1/2 feet of pavement could be monitored. The ability of the second generation CMD with a hinged guide beam to cross over the pavement crown and monitor both sides of the pavement was demonstrated. Mounting of the guide beam is not readily adaptable to all pavers as desired. Of (THE)? three pavers considered for field evaluation, the STR REX paver was the easiest to mount the guide beam.

Project Mix Design

The original mix design was a C3WR, but was changed to a C5WR mix. The coarse aggregate (gravel) and fine aggregate (natural sand) came from Hallet at Clemons.

Mix Proportions for C5WR
Approximate Quantities per Cubic Yard

Cement	618 lbs.	0.3090 ton
water	266 lbs.	
Air (Daravair R.)	6.57 oz.	
Fine Aggregate	1634 lbs.	0.8170 ton
Coarse Aggregate	1337 lbs.	0.6680 ton
WR (WRDA/HYCOL)	24.72 oz.	

Operating Procedure

Field testing began on September 1, 1983, on Iowa 330. The first day was spent becoming acquainted with the field operation ~~procedure~~. The CMD electronics failed on the third day of field testing and repairing took longer than a week.

Each morning 30 minutes were required for set-up and calibration. Set-up consisted of installing the control and readout unit, source, and signal cables. Calibration consisted of adjusting the CMD to the recorded values for the calibration block. After each day of use, the control and readout unit, source, and signal cables were removed. The internal battery for the control and readout unit required recharging after each day of use.

Load Transfer Devices

Achievement of adequate consolidation of the concrete around load transfer devices was questioned by Iowa DOT personnel. No noticeable difference in density could be detected as the CMD passed over a load transfer device.

CMD-Campbell Pacific Nuclear Gauge Correlation

A correlation between the CMD and a Campbell Pacific Nuclear Gauge (CPN) was determined. The correlation was done with the CPN in two modes, backscatter and two-inch direct transmission. The results indicate a relationship but the correlation is not as strong as anticipated (Figs. 14 and 15).

CMD-Core Correlation

After reviewing the density strip chart, locations were chosen to drill cores. The 4" diameter cores were cut into slices of 1", 2", and 4" thick to check for varying densities in the core. The cores were tested for density and percent air (Appendix D) and five cores were tested for strength (Table 1).

CMD - CPN CORRELATION FIG 19
BACKSCATTER MODE
STANDARD ERROR 1.72 lb/cu ft
c.c. 0.739

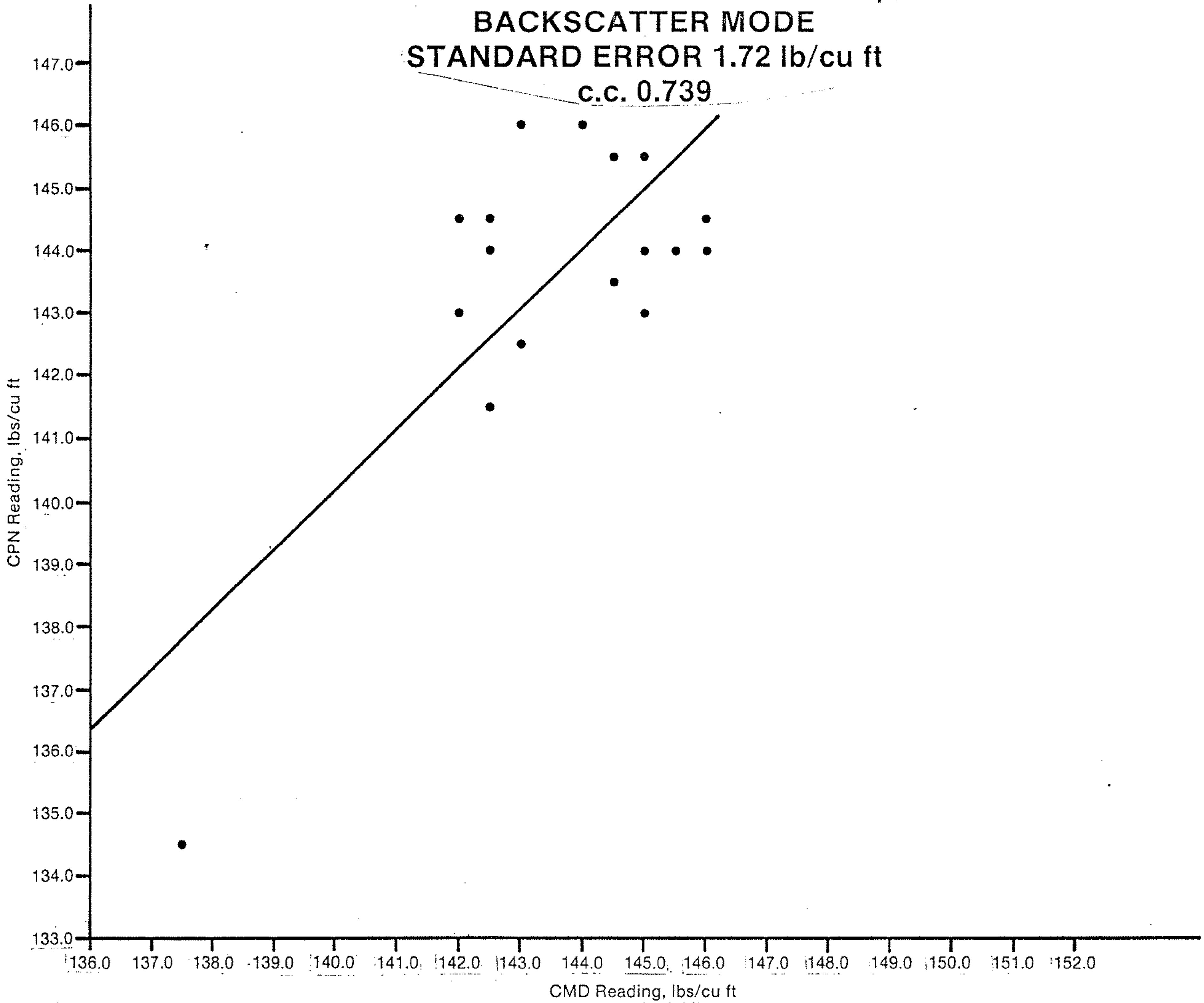


FIG 15

CMD - CPN CORRELATION
2" DIRECT TRANSMISSION
STANDARD ERROR 1.01 lb/cu ft
c.c. 0.743

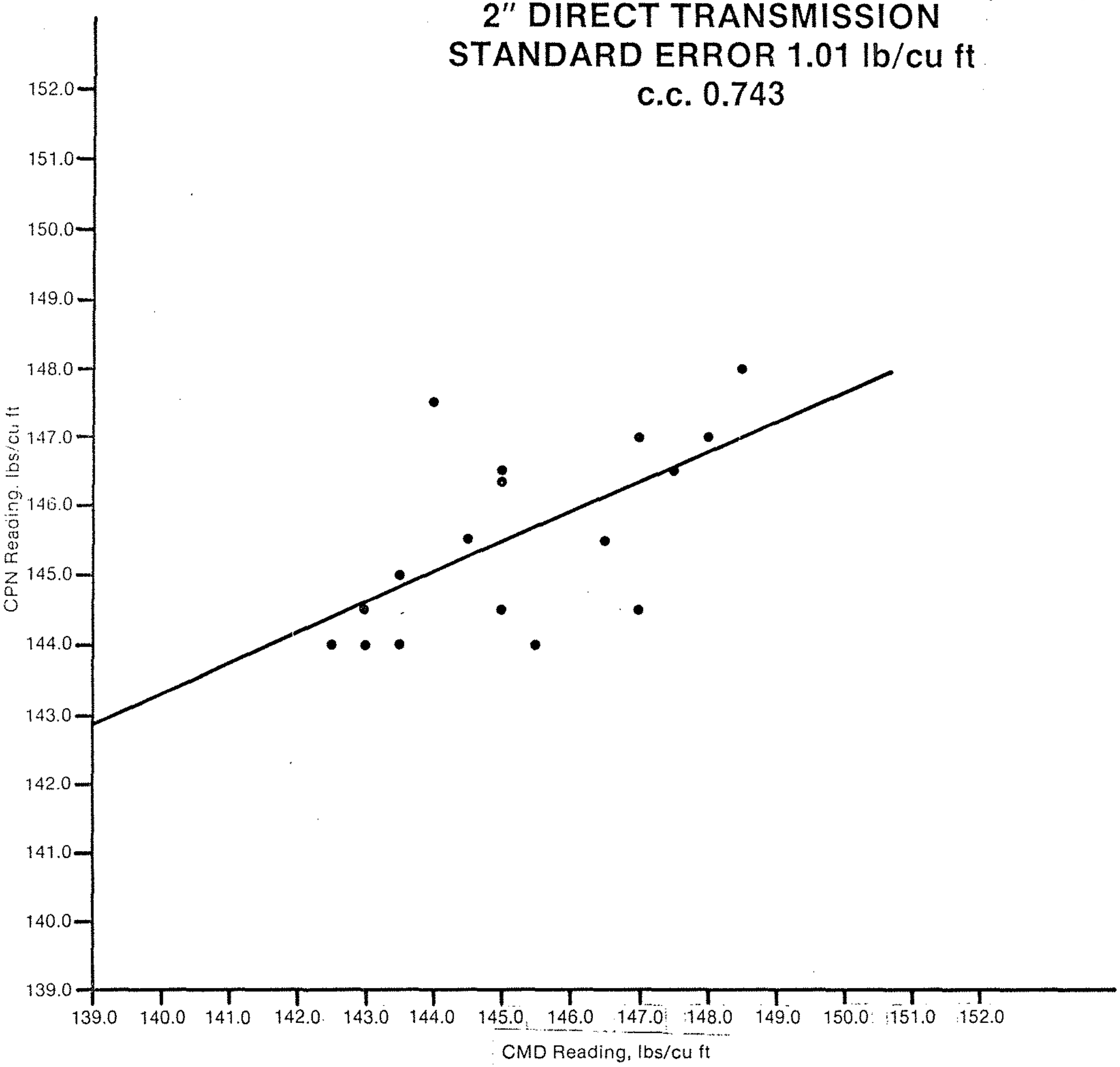
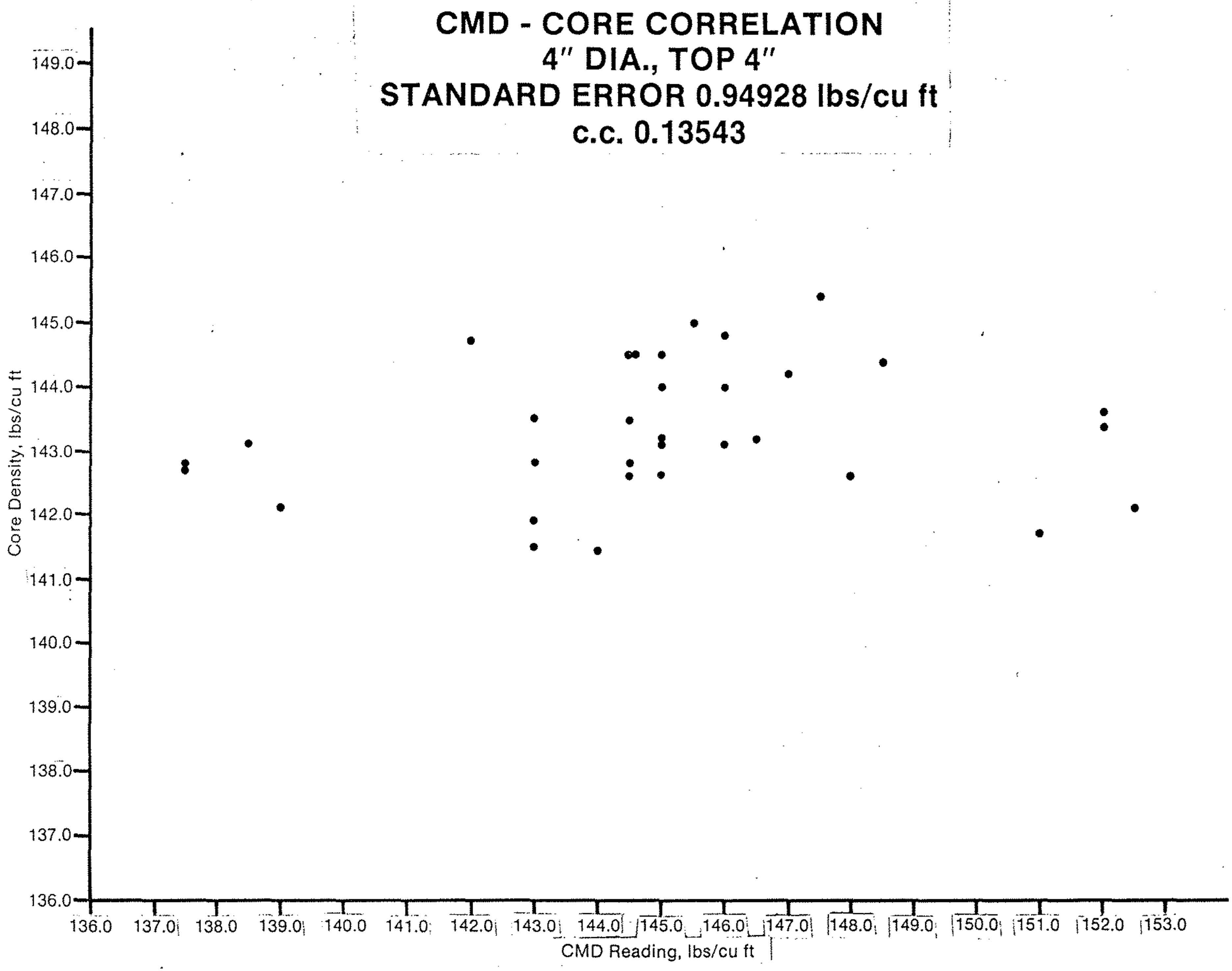


FIG 16


CMD - CORE CORRELATION
4" DIA., TOP 4"
STANDARD ERROR 0.94928 lbs/cu ft
c.c. 0.13543
Core Density, lbs/cu ft
149.0
148.0
147.0
146.0
145.0
144.0
143.0
142.0
141.0
140.0
139.0
138.0
137.0
136.0
136.0
137.0
138.0
139.0
140.0
141.0
142.0
143.0
144.0
145.0
146.0
147.0
148.0
149.0
150.0
151.0
152.0
153.0
CMD Reading, lbs/cu ft

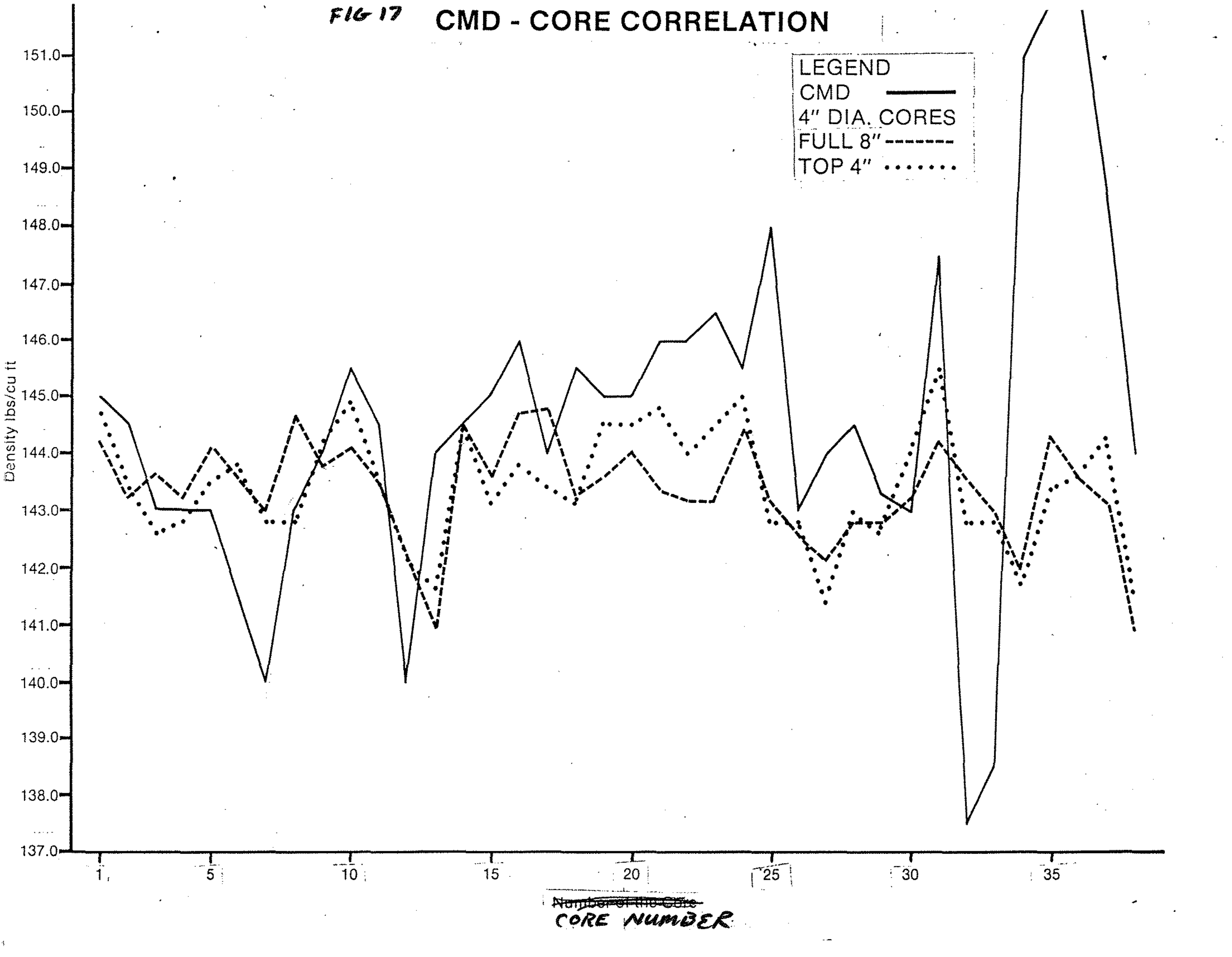


FIG 17
CMD - CORE CORRELATION
LEGEND
CMD
4" DIA. CORES
FULL 8"
TOP 4"
Density lbs/cu ft
151.0
150.0
149.0
148.0
147.0
146.0
145.0
144.0
143.0
142.0
141.0
140.0
139.0
138.0
137.0
1
5
10
15
20
25
30
35
~~Number of the Core~~
CORE NUMBER

FIG 1B

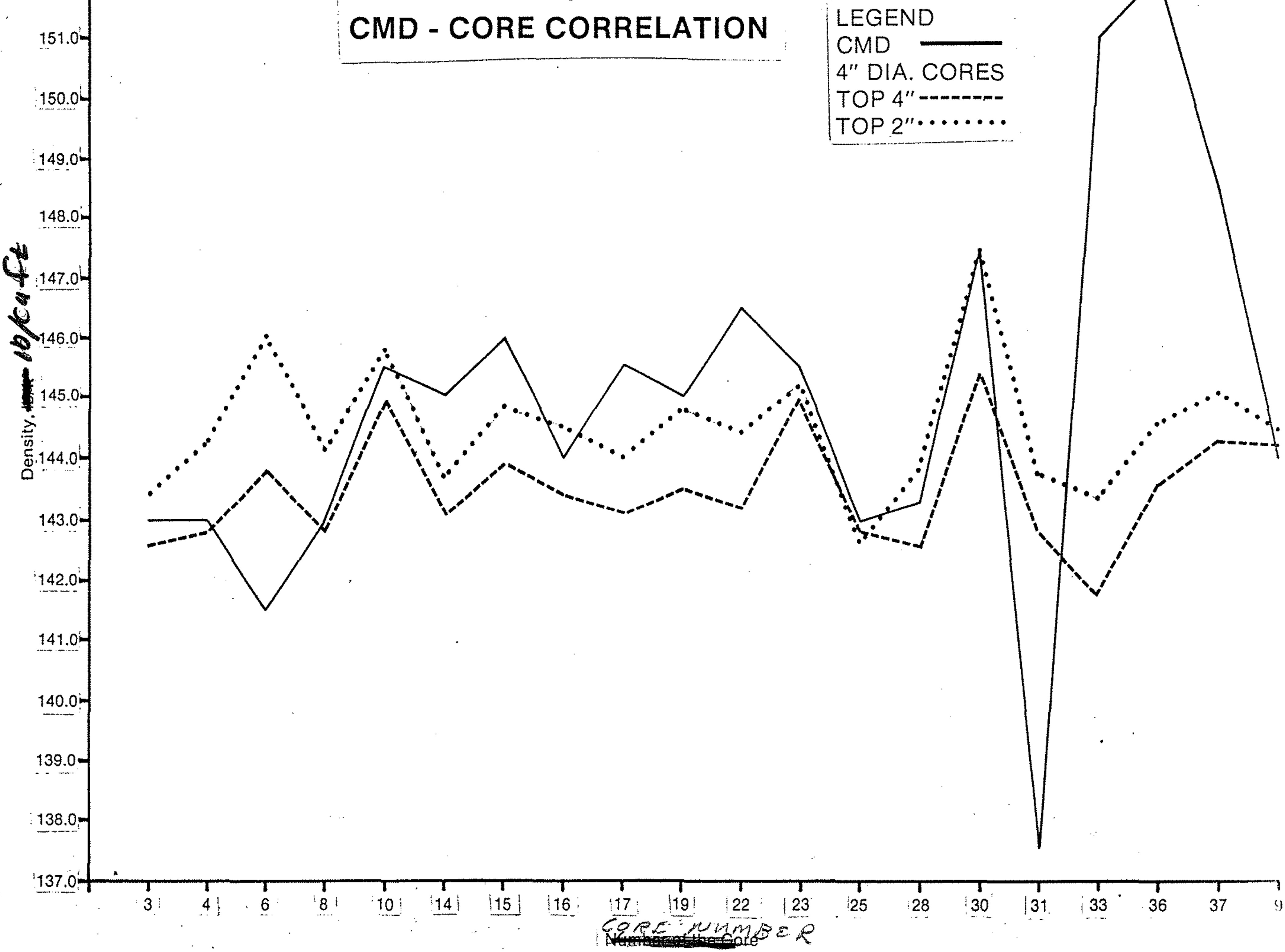

CMD - CORE CORRELATION
LEGEND
CMD
4" DIA. CORES
TOP 4"
TOP 2"
Density, lb/cu ft
152.0
151.0
150.0
149.0
148.0
147.0
146.0
145.0
144.0
143.0
142.0
141.0
140.0
139.0
138.0
137.0
3
4
6
8
10
14
15
16
17
19
22
23
25
28
30
31
33
36
37
9
CORE NUMBER
~~Number of the Core~~

TABLE 1
Strength & Density of 4" Diameter 8" Long Cores

Station Number	CMD Reading lbs./cu.ft.	Core Density lbs./cu.ft.	Strength PSI
184+36	140.0	143.5	3950
185+35	145.0	144.4	4500
188+66	147.5	144.0	4130
207+32	146.0	144.6	4820
215+00	144.0	144.6	5250

The correlation of the CMD with the 8" long cores yielded a standard error of 0.7885 lbs/cu ft and a correlation coefficient (CC) of 0.074651, a very low degree of correlation. Since the depth of influence is 4-1/2", the top 4" of the cores were correlated with the CMD (Fig. 16). The standard error was 0.94928 lbs/cu ft and a CC of 0.13543, which is better than the 8" core but still exhibits a low degree of correlation. The top 2" of the core yielded a standard error of 1.025 lbs/cu ft and a CC of 0.1937 which is better than the top 4" but still a low degree of correlation. The CMD-core correlation is not as good as anticipated. Graphing the CMD and core density yields an insignificant, but general relationship (Figs. 17 and 18).

Reproducibility

Several tests were conducted to check the reproducibility of the CMD. In the laboratory the CMD was placed on the calibration block and the density varied ± 1.5 lbs/cu ft (Fig. 19). During field testing, the CMD was held in a stationary position and the density again varied ± 1.5 lbs/cu ft The density traces were compared at locations where the paver was stationary and the CMD was traversing. The CMD would reproduce the density trend, but would show substantial differences in individual locations (Fig. 20).

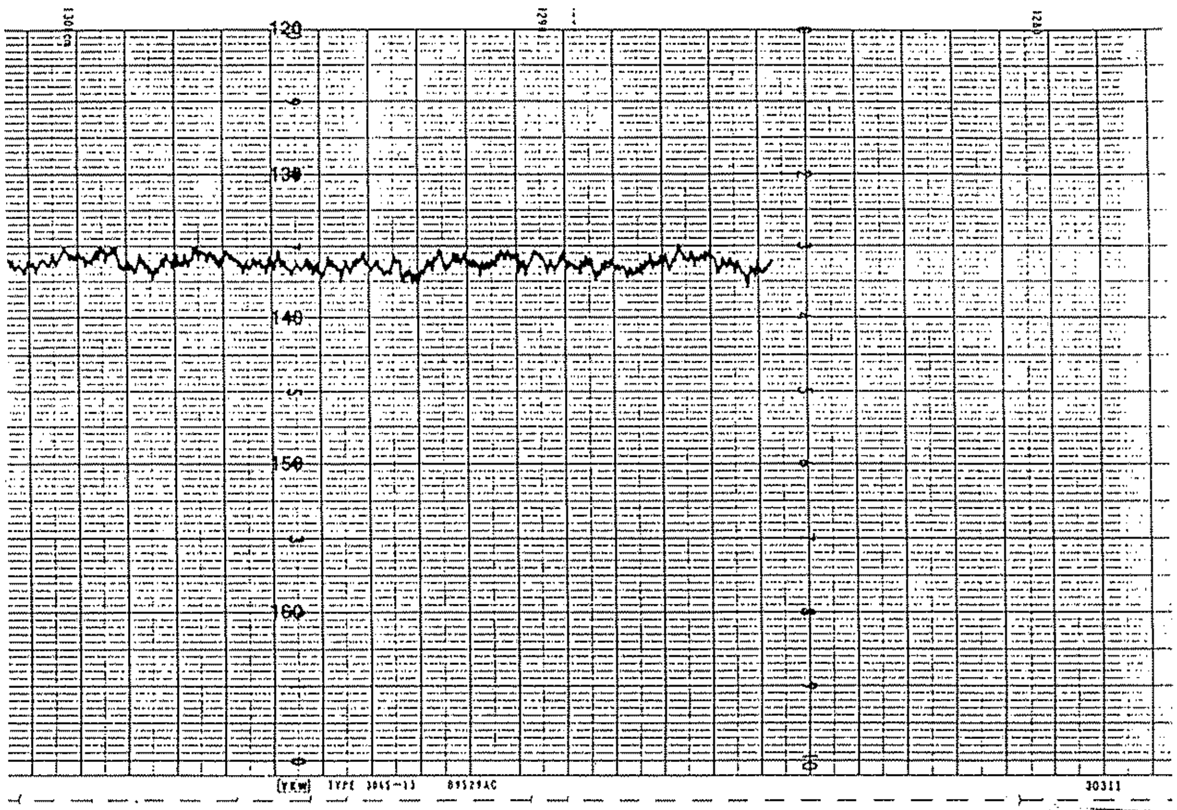


FIG 19 VARIATION OF DENSITY ON THE CALIBRATION BLOCK, 5 SECOND TIME SETTING

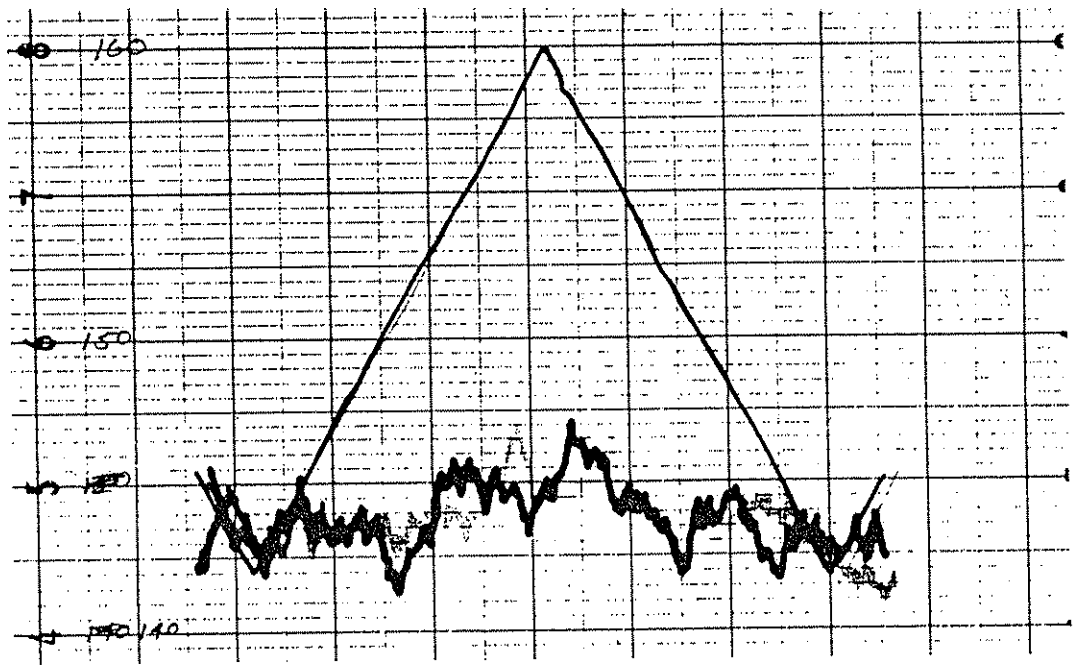


FIG 20 DENSITY TRACE COMPARISON

Cores were taken from a cross section at three locations and the densities compared. The individual densities exhibited a low correlation with the CMD, but did exhibit a higher correlation of density trends (Figs. 21, 22 and 23).

Electronic Problems

It is the opinion of the investigators that the electronics of the second generation CMD are not durable enough for field operation. The first generation CMD had no electronic malfunctions that prevented field operation. The only problem attributed to electronic difficulty of the first generation CMD was randomly occurring spikes on the density strip chart (Fig. 24).

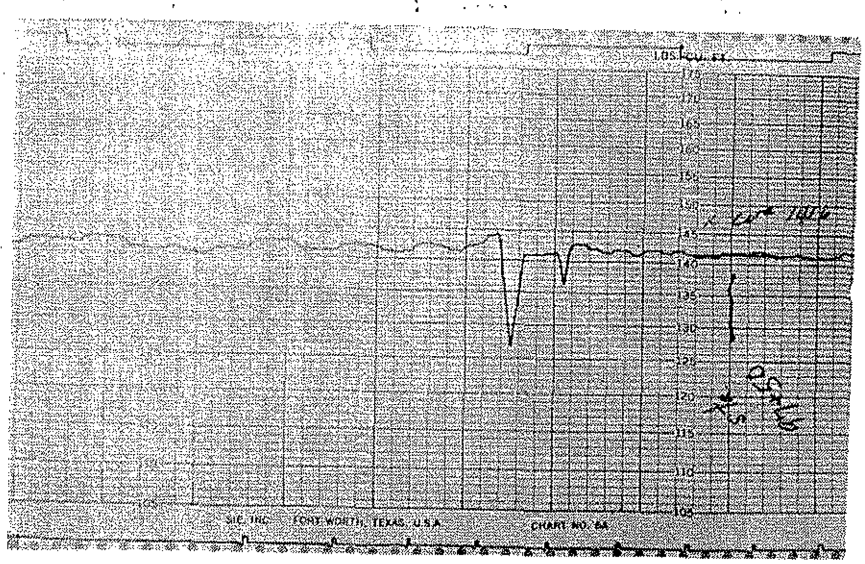


FIGURE 24
Trace displaying "Spikes"

The electronics of the second generation as received did not function properly. The CMD would not read density or air gap. Two switches, an integrated circuit (that was not readily available) and one week were necessary to repair the CMD before laboratory evaluation could begin. There were several times the electronics malfunctioned and had to be repaired before continuing operation.

FIG - 21

CMD - CORE CORRELATION
STATION 184+29
TRAVERSING LEFT TO RIGHT

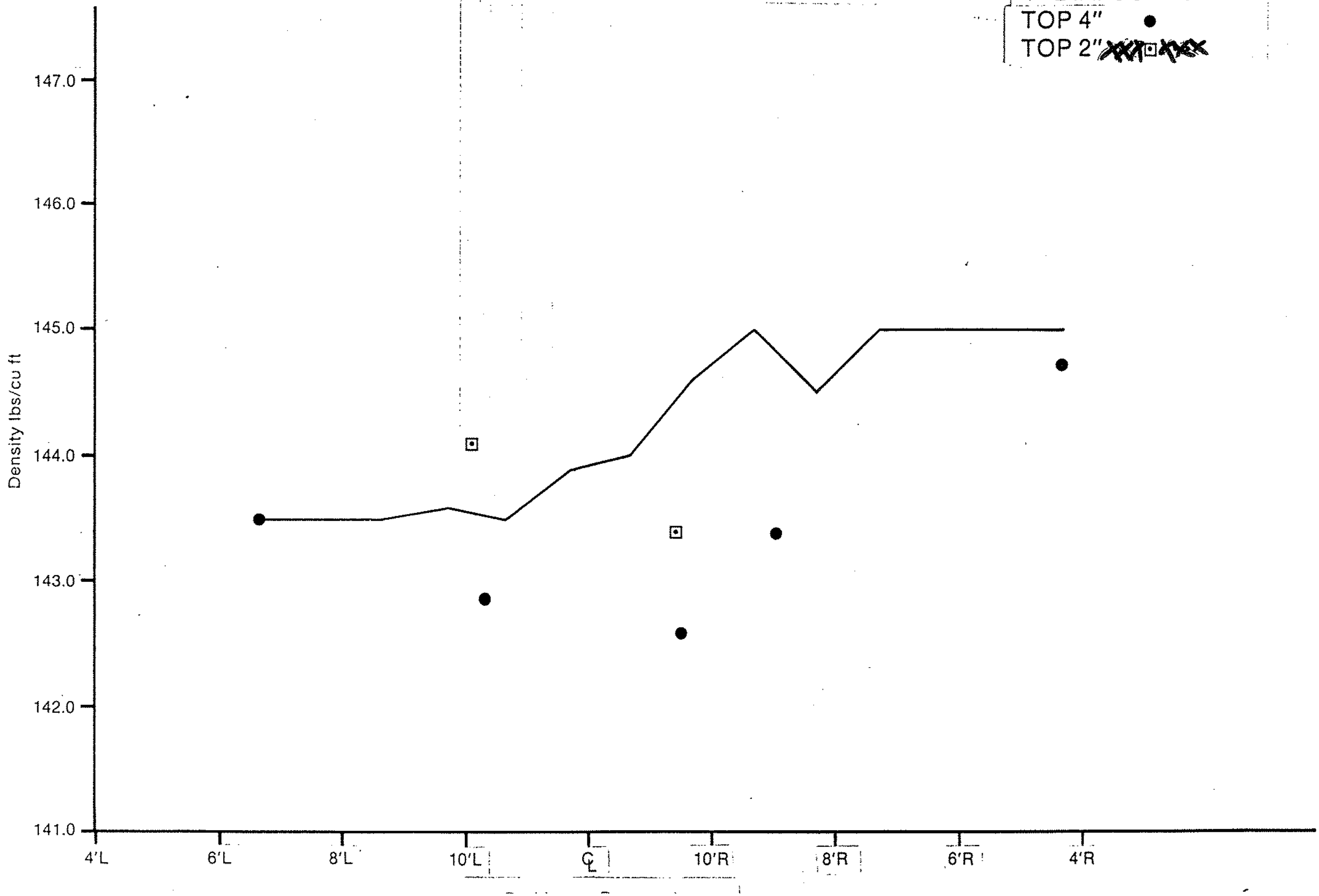


FIG 22

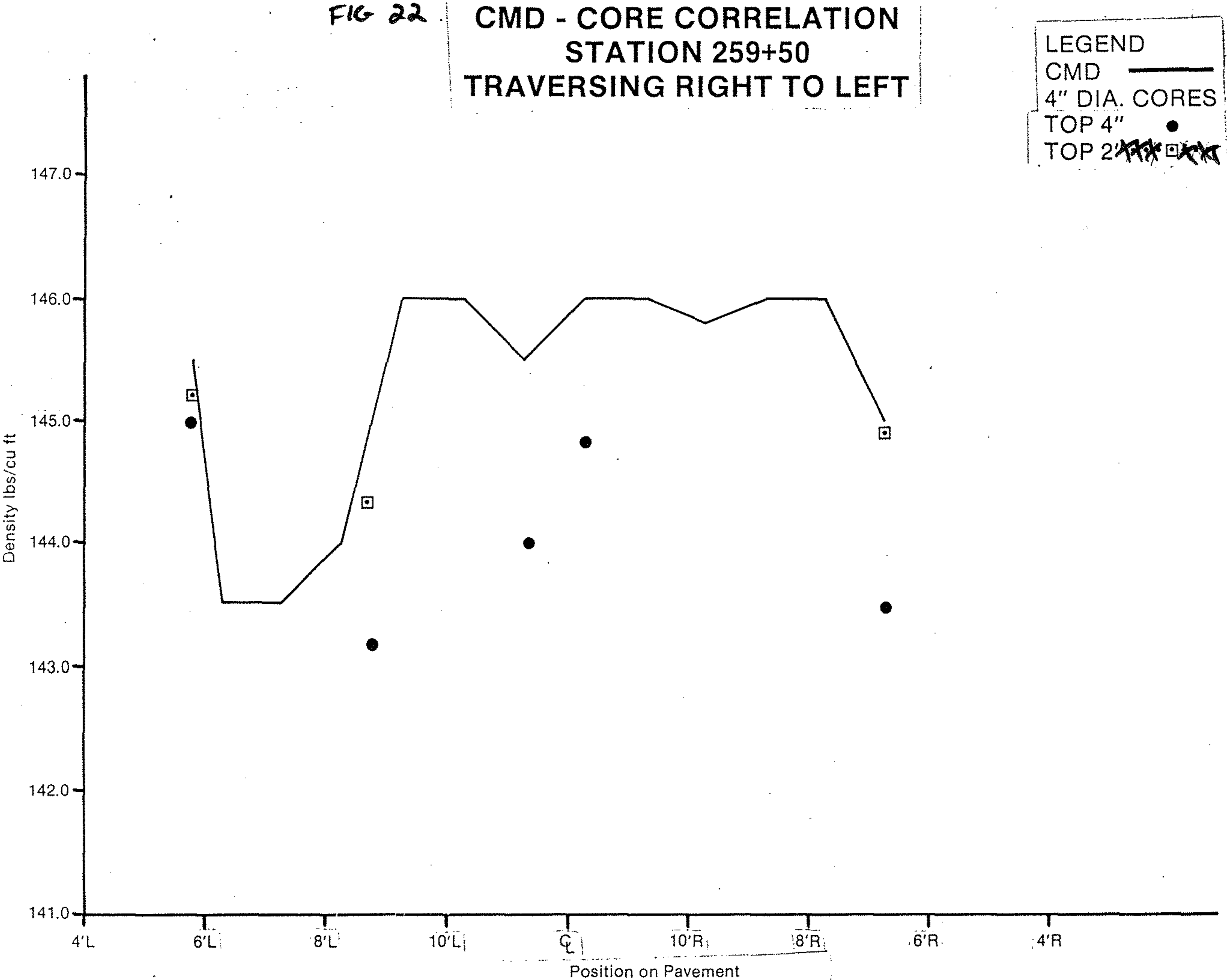
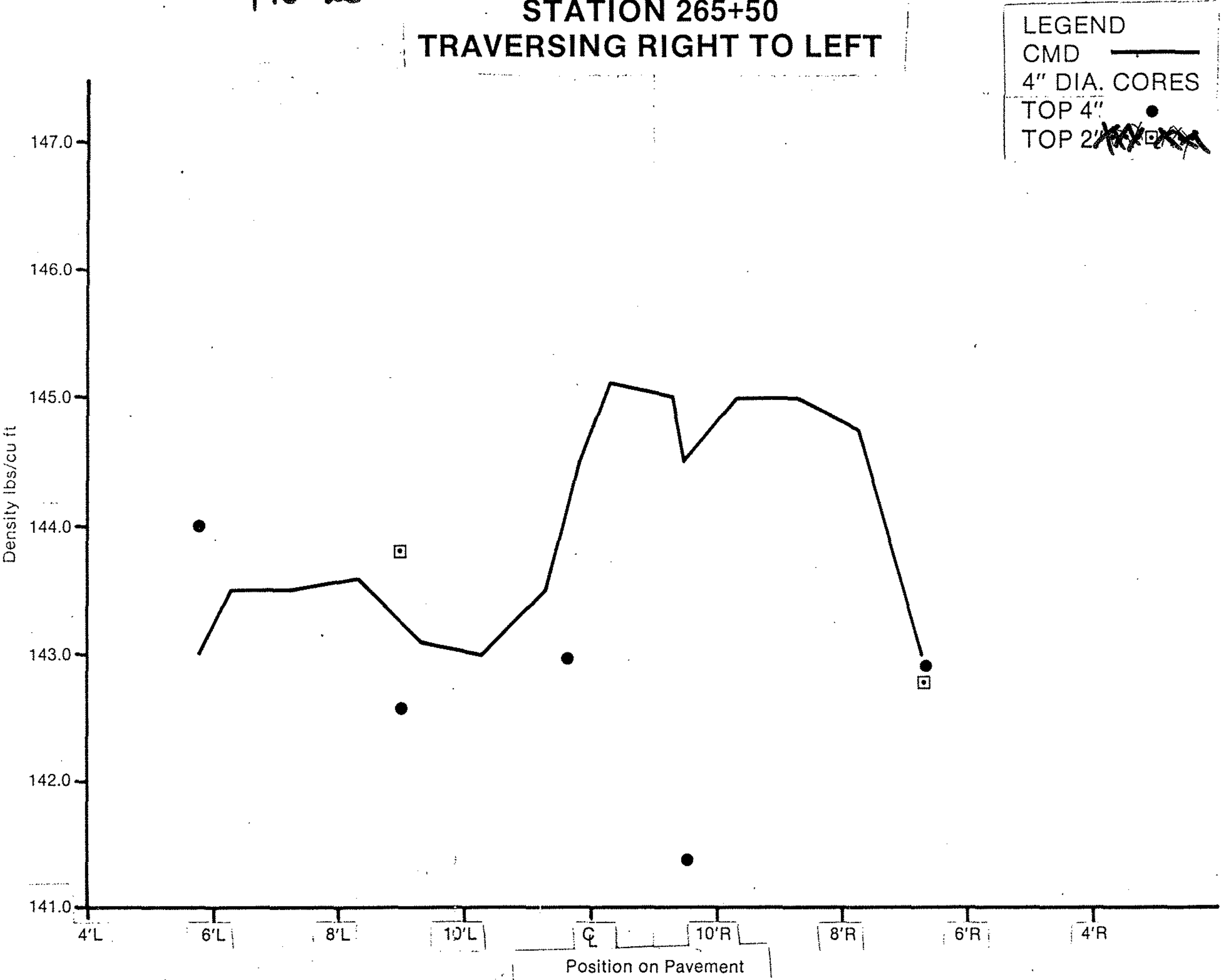

CMD - CORE CORRELATION
STATION 259+50
TRAVERSING RIGHT TO LEFT
LEGEND
CMD
4" DIA. CORES
TOP 4"
TOP 2"
Density lbs/cu ft
147.0
146.0
145.0
144.0
143.0
142.0
141.0
4'L
6'L
8'L
10'L
℄
10'R
8'R
6'R
4'R
Position on Pavement

FIG 23

CMD - CORE CORRELATION
STATION 265+50
TRAVERSING RIGHT TO LEFT



The electronics of the second generation CMD are also susceptible to commercial band radio waves (Fig. 25). During field operation, the use of a commercial band radio on the paver would disrupt the CMD's electronics. Improper functioning of the CMD would continue for a short period after the use of the radio.

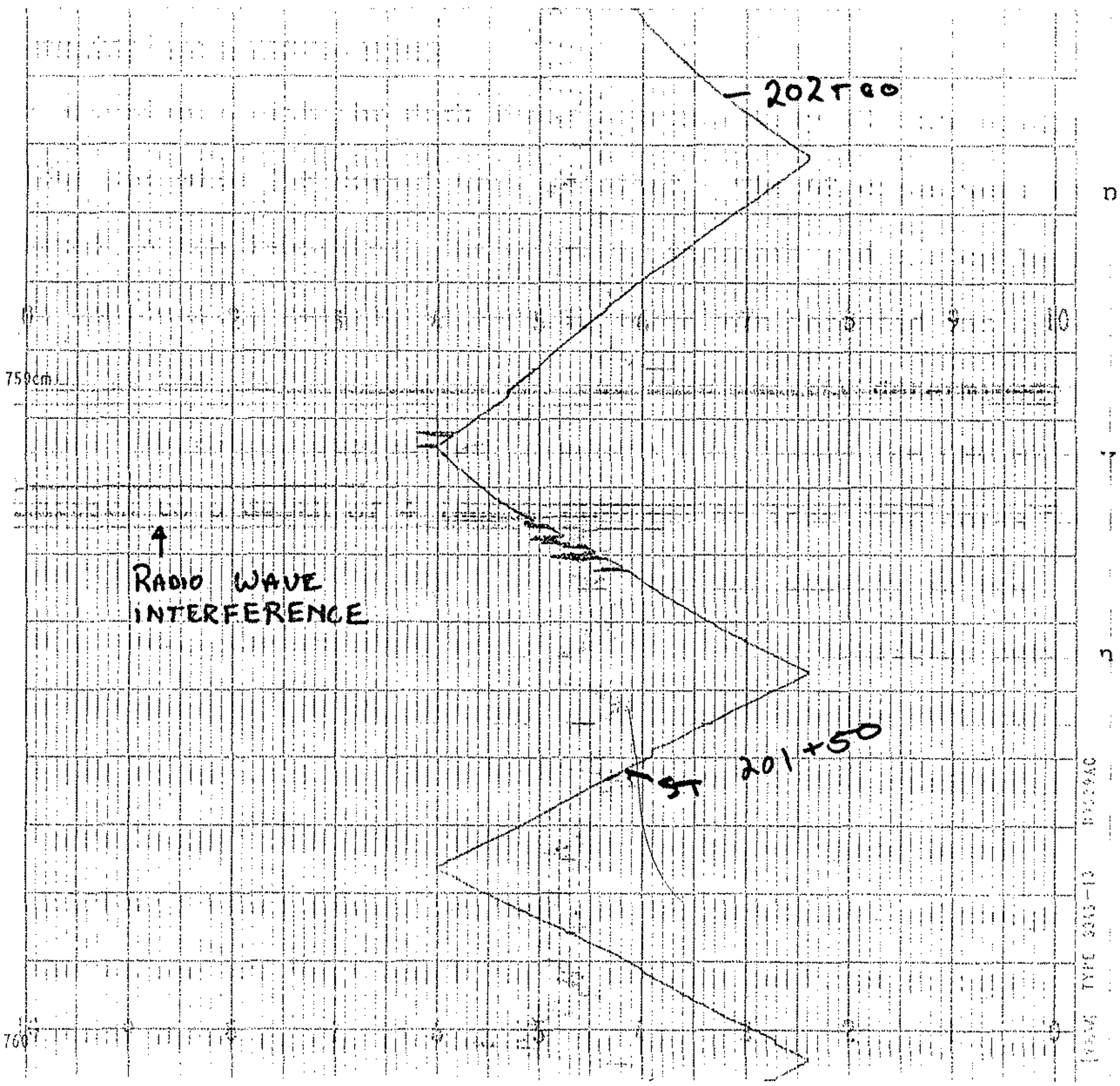


FIG 25 INTERFERENCE BY RADIO WAVES ON THE CMD READING