78-3

AN EVALUATION OF THE

CONSOLIDATION MONITORING DEVICE

IOWA

HIGHWAY DIVISION

OFFICE OF MATERIALS

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Director

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HR-1013, Final Report, "An Evaluation of the Consolidation Monitoring Device"

Attached is one copy of the final report of the research project noted above. The Consolidation Monitoring Device (CMD) is attached to the rear of a Slipform Paver and using a 500 mCi Cesium source provides a continuous readout of the density of the plastic concrete. The evaluation demonstrated that until there was either automatic control of the one inch air gap or a correction for deviations from one inch, the accuracy or usefullness could not be determined.

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AN EVALUATION OF THE CONSOLIDATION MONITORING DEVICE

FINAL REPORT

FOR

IOWA DEPARTMENT OF TRANSPORTATION

RESEARCH PROJECT HR-1013

CONDUCTED FOR THE

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

UNDER

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TASK ORDER NO. 10

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AN EVALUATION OF THE CONSOLIDATION MONITORING DEVICE

SUMMARY

Purpose and Scope

The Iowa Department of Transportation research project HR-1013 is the evaluation of a prototype continuous monitoring nuclear density unit. The Unit, the Consolidation Monitoring Device (CMD), mounts on the rear of a slip-form paver and measures the density of the concrete while still in the plastic state. The evaluation performed determined the usefulness, accuracy, precision and reproducibility of the unit. The CMD was calibrated and tested in the laboratory for one week before field evaluation. The field evaluation consisted of monitoring at least 5 miles of paving and then correlating the CMD data with two conventional density methods. The two supplemental methods were density measurement with a Troxler nuclear gauge and densities obtained from core samples.

Conclusions

The results of the evaluation testing indicated to the research investigators that in the present state-of-the-art, the CMD is not a useful or reliable instrument. These conclusions are based mainly on the fact that under field conditions, the 1 inch (25.4 mm) air gap is difficult to maintain. Once the air gap varies slightly from the prescribed distance, the accuracy and reproducibility of the CMD readings suffer.

Mounting and adjustment problems were also experienced during testing of the CMD. The mounting of the traverse bar was not a bolt-on attachment to the slip-form paver. The contractor needed to add extra mounts to his paver in order to properly attach the CMD. Also during the course of evaluation, mechanical problems developed in the vertical adjustment mounts. When properly operated, there is no significant exposure from the radioactive source.

Recommendations

The investigators believe that some modification must be made to either measure the 1 inch (25.4 mm) air gap between the sensor head and the concrete surface and compensate for the difference or automatically control the air gap. A modification of this type would also greatly improve the operating ease of the CMD unit.

INTRODUCTION

On June 5, 1978, the Iowa Department of Transportation (Iowa DOT) Statement of Work for the Consolidation Monitoring Device was approved by the Federal Highway Administration (FHWA). The evaluation to be performed will determine the dependability, usefulness, accuracy, and reproducibility of a device which continuously monitors the consolidation of plastic Portland Cement Concrete (PCC) pavement under field conditions.

Continuous monitoring of PCC pavements which are still in the plastic state could prove to be beneficial, especially in the area of improved quality. Quality improvements at a reduction in costs are possible since inadequately consolidated concrete can be avoided by immediate correction. Also by insuring adequate consolidation, strength specification requirements may be attained without employing the practice of using excess cement. The advantage of continuous monitoring may result in reduction in the quantity of cement and thus a savings in cost.

WHAT IS THE CMD?

The Consolidation Monitoring Device (referred to as the CMD) is an instrument which is capable of continuous monitoring of freshly paved concrete. The CMD is a prototype instrument which utilizes backscattered gamma rays to determine concrete density. The gamma rays are massless Not!! high energy photons which are emitted from a 500 mCi Cesium ^{137} source. A sodium iodide photomultiplier sensing unit detects the quantity of back-scattered gamma rays which is then converted into a direct density readout on the control and readout unit. A 1 inch (25.4 mm) air gap is maintained between the sensor head and the concrete surface (Photo 1). The source/sensor unit can either traverse back and forth at a speed of 17 ft./min. (5.2 m/min.) across the 11'6" (3.5m) traverse beam which is mounted to rear of a slip-form paver, or it can be held in a stationary position within the traverse.

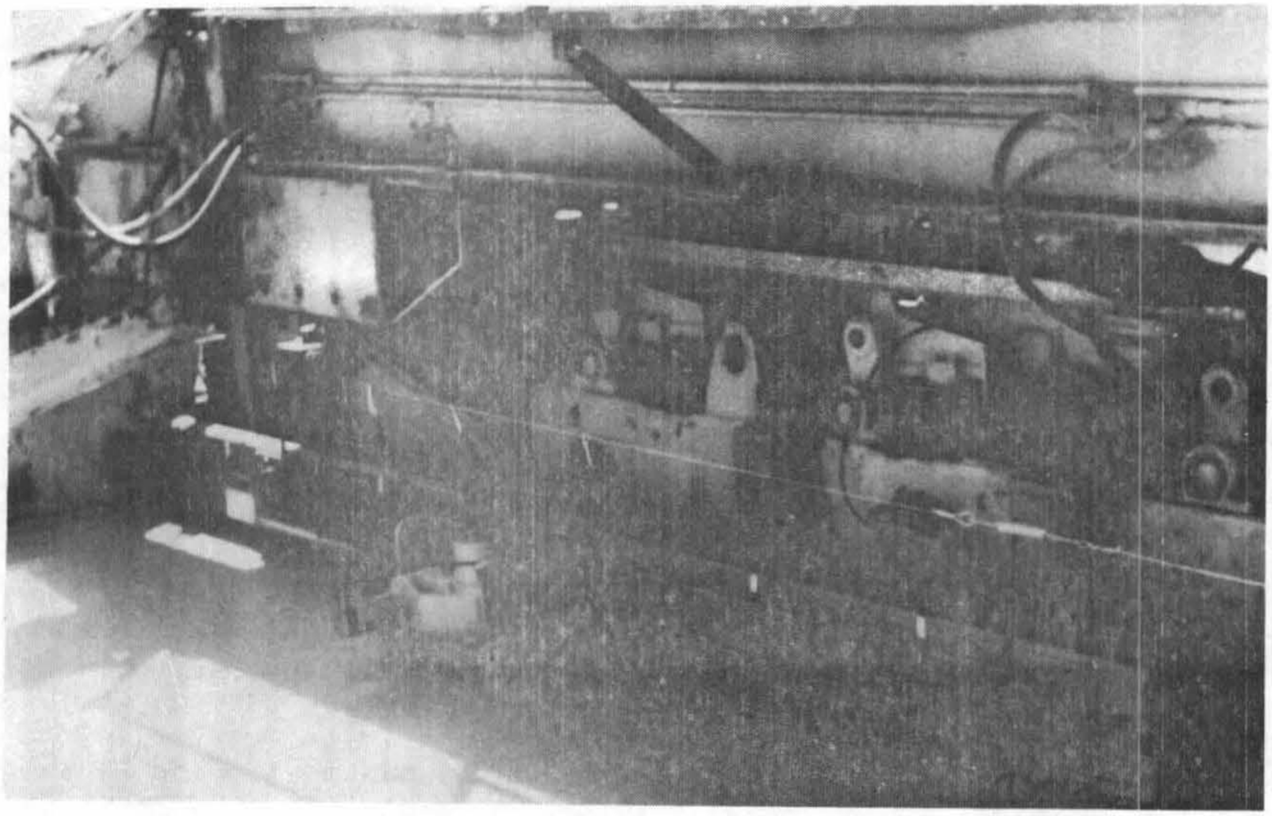


Photo 1

The CMD in a traversing mode.

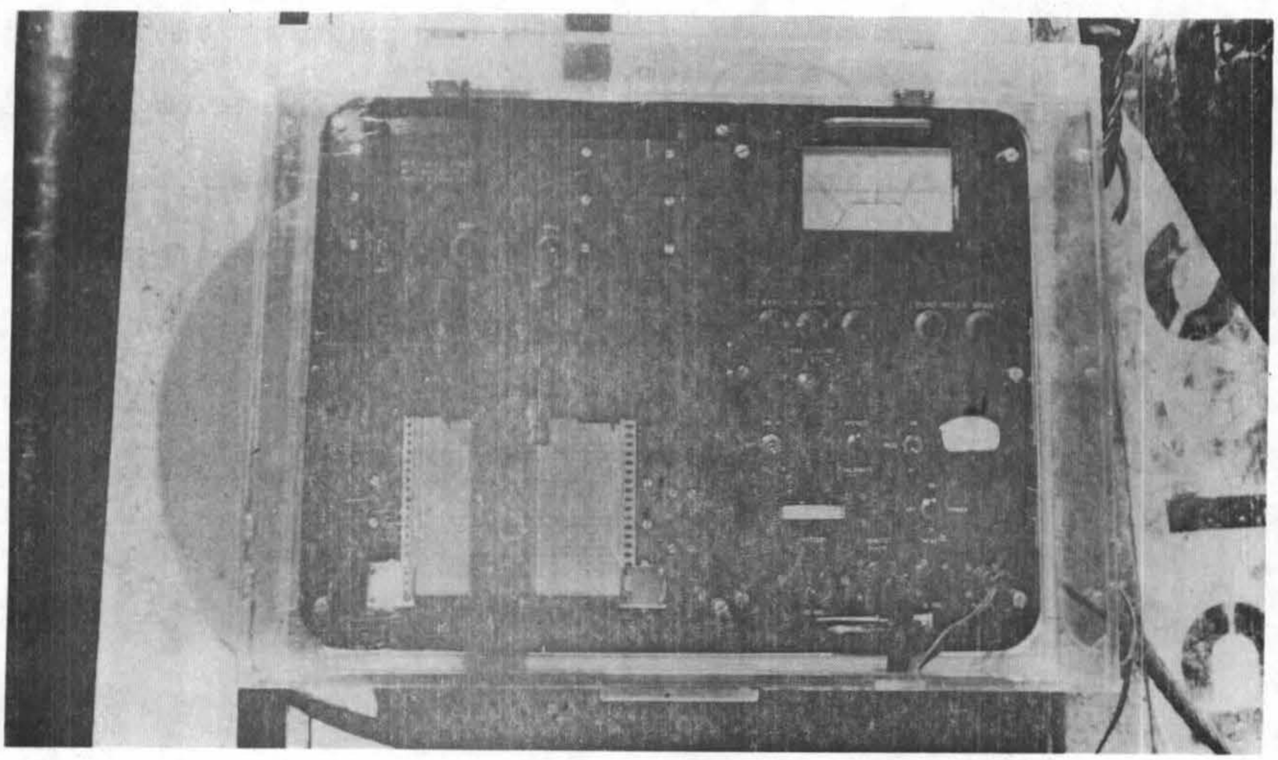


Photo 2

The control and readout unit.

The CMD was developed by Rexnord Inc. of Milwaukee, Wisconsin under a contract with the FHWA.[1] The developmental specifications required an instrument which would be relatively small, capable of monitoring at forward surface speeds up to 30 ft./min. (9.1 m/min.), and to a depth of 3.5 to 4 inches (89 to 102 mm). An internal power supply was also determine to be a necessity. The final CMD instrument package is made up of the following components:

Control and readout unit (Photo 2)
Source/sensor unit
Source holder with Cesium ^{137} source
Storage shield for source
Traversing mechanism
Calibration block
Sensor assembly and cables

WORK PLAN

The Iowa DOT work plan stated the testing to be performed to determine the usefulness, accuracy, precision, and reproducibilty of the CMD as a plastic PCC pavement continuous monitoring instrument. An initial one week laboratory testing period was scheduled. Field testing and evaluation were planned for the next 6 weeks. Field evaluation called for the monitoring of a least 5 lane-miles (8.05 km) of a single project. A final week of laboratory testing was scheduled after completion of the field testing. The laboratory testing was conducted at the Iowa DOT Materials Laboratory in Ames. The field testing site for the CMD was on the Audubon RF-44-3(6) and Guthrie TQF-44-4(11) projects.

Before receiving the 500 mCi Cesium ^{137} source, a license to use the CMD was obtained from the United States Nuclear Regulatory Commission. During operation, the CMD was under the direct supervision of the Principal Investigator or a designated qualified person.

EVALUATION OF THE CMD

Laboratory Testing Plan

The beginning of the one week laboratory testing period was used first to acquaint the testing personnel with the CMD. After becoming familiar with the operating techniques, laboratory testing and calibration were initiated. The laboratory evaluation consisted of testing the following areas:

1. Radiation exposure at various distances from the CMD in the operating mode.
2. Calibration of the CMD in accordance with the stated calibration procedure. (Appendix A)
3. The effect of changes in the air gap between the source/sensor unit and the concrete surface.
4. The determination of the area of influence of the CMD. (edge effects)
5. The determination of the depth of influence of the CMD.
6. Calibration of Troxler moisture/density gauge for use on plastic concrete.

Radiation and Safety

Due to the large size of nuclear source the CMD requires, radiation exposure quantities were of primary concern. The 500 mCi Cesium ^{137} source is quite large as compared to conventional commercial moisture/density gauges which utilize

3 - 50 mCi sources. A radiation survey of the CMD was taken with the device in the operating mode and setting on the calibration block. The survey meter indicated the radiation level at the following distances from the source to be:

1 ft. (.3m)	1.30 millirems per hour
2 ft. (.6m)	0.45 millirems per hour
5 ft. (1.5m)	0.15 millirems per hour
10 ft. (3.0m)	0.04 millirems per hour

All personnel working directly with the CMD were required to wear a film badge to monitor radiation exposure. The badges for the 3 research investigators registered no radiation exposure over the two-month testing period (Appendix B). The main investigator also carried a dosimeter so that he could readily check his daily exposure. The dosimeter registered a total exposure of 17 milliroentgens for the two month period. The above values indicate that the CMD is a well-shielded and safe instrument when properly used. A leak test on the Cesium ^{137} source was conducted before delivering the CMD to the next state (Illinois). The results of the test indicated no radiation leakage.

Laboratory Calibration

The calibration of the CMD was a two procedure process. The first calibration procedure used two fresh concrete samples consisting of the same materials as being used on the field construction project. The usage of like material was to negate possible effects of chemical composition of the concrete mix on the CMD density readings. Experiences with other nuclear instruments have shown that difference in composition of calibration specimens and field samples can cause inaccurate readings.

The second calibration procedure is designed to correct for day-to-day variations in electrical circuit characteristics of the CMD. This calibration uses a magnesium/aluminum block and a steel insert as a daily check on the laboratory calibration settings. The zero and span of the CMD readout is adjusted (if needed) by resetting the readout to correspond to a low density reading (magnesium/aluminum block only) and a high density reading (magnesium/aluminum block with steel insert) as determined in the laboratory testing.

A. Calibration on Fresh Concrete

Laboratory calibration began with the assembly of four of the six 2 cubic foot (0.056 m^3) wooden molds furnished with the CMD. Rubber base sealant was used to seal the inside joints to insure a watertight mold. The exact volume of each of the 4 molds was determined by weighing them before and after filling the molds with water. It was decided that a pointer system was needed to indicate when the molds were level full. An arm, which slipped over the sides of the molds, was built with 3 adjustable pointers attached to it. The 3-point system worked very well in two respects; for indicating full and level. (Photo 3)

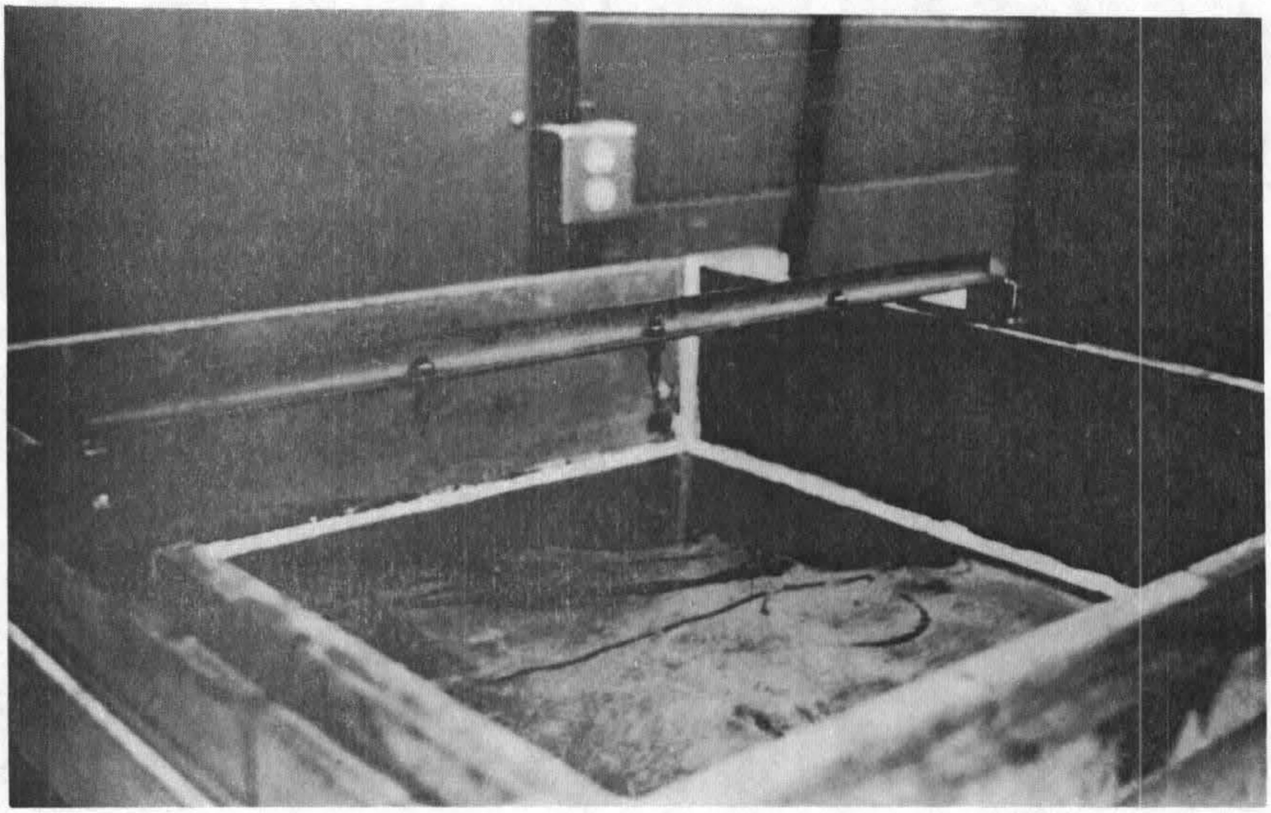


Photo 3
The pointer system for mold volume determination.

After determining the volumes of the molds, two samples of concrete were mixed. One mix was designed to be a high air content, high w/c ratio, low density and the second was low air content, low w/c ratio, high density mix. In the first calibration effort, the two mixes had a narrow density spread, 147.9 lbs./cu.ft. (2370 kg/m^3) for the high density and 140.6 lbs./cu.ft. (2250 kg/m^3) for the low density. The high-low range of 7.3 lbs./cu.ft. (120 kg/m^3)was determined to be marginal for a proper calibration of the CMD. It was theorized that during consolidation of the calibration concrete as outline in the CMD instrument manual, the vibrator was dispelling the entrained air from the high air content mix.

It was decided that another attempt would be made at achieving two plastic concrete samples with a 12 - 15 lbs./cu.ft. (190 - 240 kg/m^3) difference in densities. The following day, being careful not to over-vibrate the high air concrete in the molds, a density difference of 13.6 lbs./cu.ft. (220 kg/m^3) was attained. The low density sample had a density of 136.2 lbs./cu.ft. (2180 kg/m^3) with an air content of 11.2%. The high density sample was determined to be 149.8 lbs./cu.ft. (2400 kg/m^3) with an air content of 3.6%. The 13.6 lbs./cu.ft. (220 kg/m^3) range was considered to be adequate for the high-low calibration set. The laboratory calibration data is in Appendix C .

B. Calibration on the Calibration Block

As mentioned earlier, a calibration check to correct for day-to-day variations within the CMD is needed. The check developed utilizes the magnesium/aluminum block and steel insert sheet. After calibration on the plastic concrete was completed, CMD readings were determined with the unit properly placed on the calibration block.

The CMD density reading on the magnesium/aluminum block without the steel insert was 132.3 lbs./cu.ft. (2120 kg/m^3). The reading with the steel insert in place was 149.5 lbs./cu.ft. (2400 kg/m^3). At the beginning of each days field monitoring, the

CMD source/sensor unit was placed on the calibration block and adjusted, if needed, to correspond with these two values.

Strip Chart Density Trace Characteristics

The time constant used for averaging the concrete density readings from the photomultiplier sensing unit could be varied from 0.5 seconds to 10 seconds. The length of the time constant averaging period had a direct relationship with the variation of the density trace on the strip chart. A 10 second count resulted in a relatively uniform and smooth trace; while a 0.5 second count produced a "saw-tooth" trace. The characteristic traces for different time constant settings as shown below:

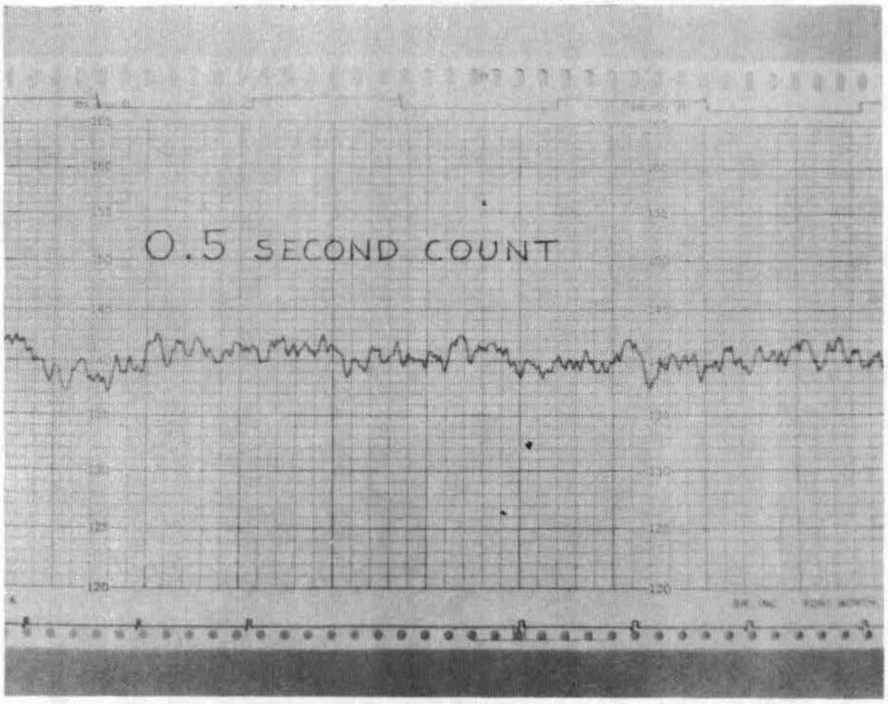


Photo 4
Trace during 0.5 second setting.

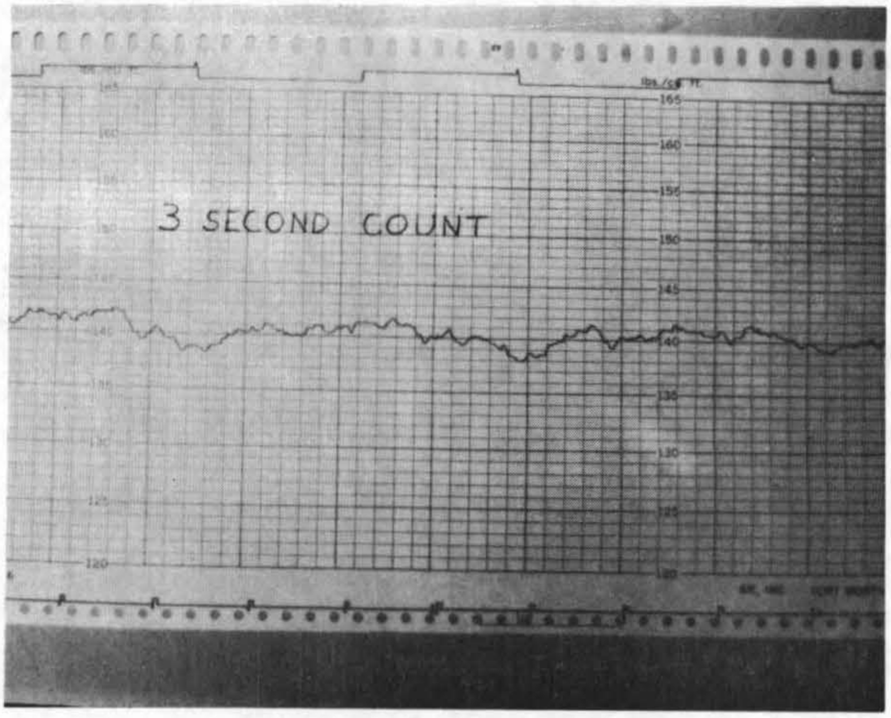


Photo 5

Trace during 3 second setting

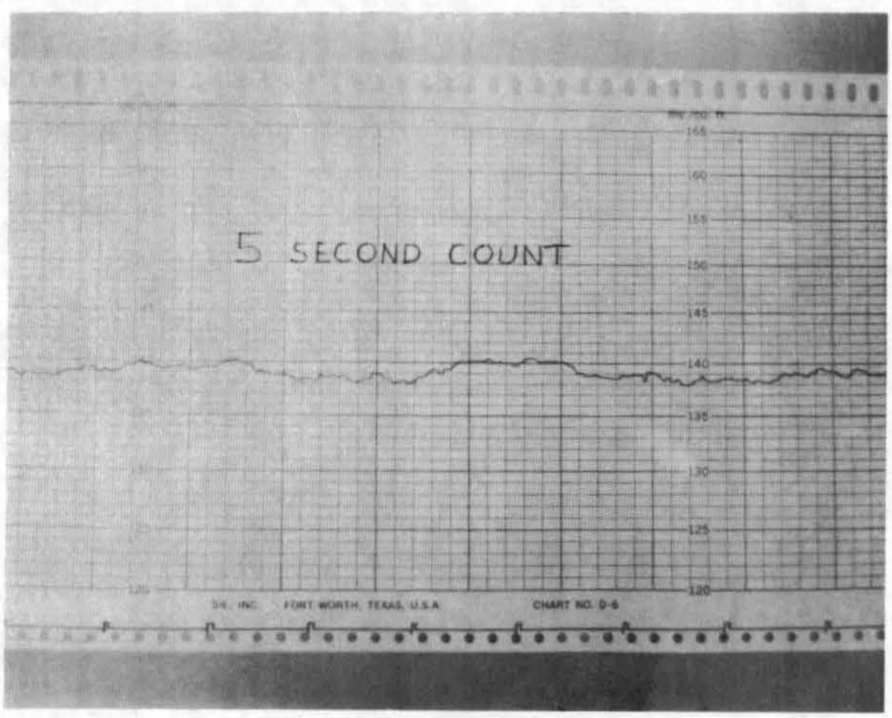


Photo 6

Trace during 5 second setting

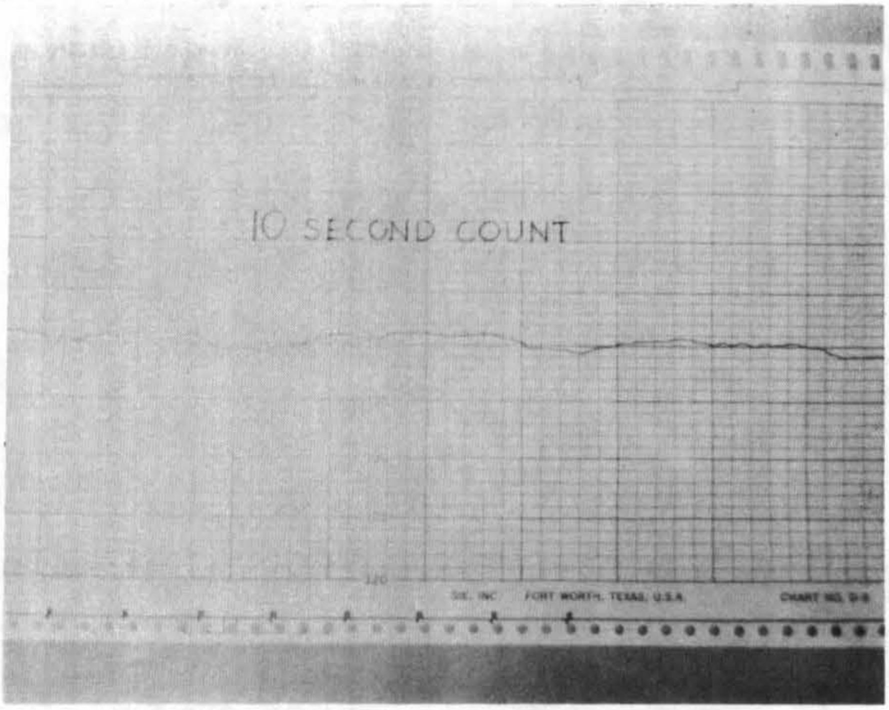


Photo 7
Trace during 10 second setting.

Air Gap Characteristics

The CMD is an "air gap" instrument which was developed to be suspended 1 inch (25.4 mm) above the pavement during monitoring. Since the CMD was calibrated for 1 inch (25.4 mm) air gap, variances, plus or minus, will affect the accuracy of the density readings. Maintaining this 1 inch (25.4 mm) gap during field operation was thought to be the most difficult variable to control. Therefore, testing was done to determine the effect of changes of the air gap. The data collected during testing is as follows:

Air Gap	CMD Readings	Air Gap	CMD Readings
.85 inches	144.0 lbs./cu.ft.	1.05 inches	141.5 lbs./cu.ft.
.90	143.5	1.10	141.2
.95	142.8	1.15	140.5
1.00	142.2	1.20	139.9

The testing revealed that a 0.05 inch (1.3 mm) change in the air gap results in a corresponding 0.6 lbs./cu.ft. (10 kg/m^3) change in the CMD density readout of 142.2 lbs./cu.ft. (2280 kg/m^3) for a 1 inch (25.4 mm) air gap. This is equivalent to a 1% error for each 0.12 inch (3.0 mm) plus or minus change of the air gap.

Area of Influence (Edge Effects)

One characteristic which all nuclear density gauges have in common is inaccurate readings as the area of influence intercepts an edge. Tests on a concrete block were conducted with the source/sensor unit to determine the area of influence of the CMD. Monitoring with the CMD was done in three different orientations; source/sensor parallel to the edge, and source/sensor perpendicular to the edge with the source to the outside and then with the sensor closer to the edge.

The testing revealed that when an edge is closer than 5 inches (130 mm) from the centerline of the CMD source/sensor unit, the readings become erratic. The density readings first increased as an edge came within 5 inches (130 mm), and then dropped off suddenly. A 7 inch (180 mm) minimum edge distance is recommended to insure accurate monitoring.

Depth of Influence

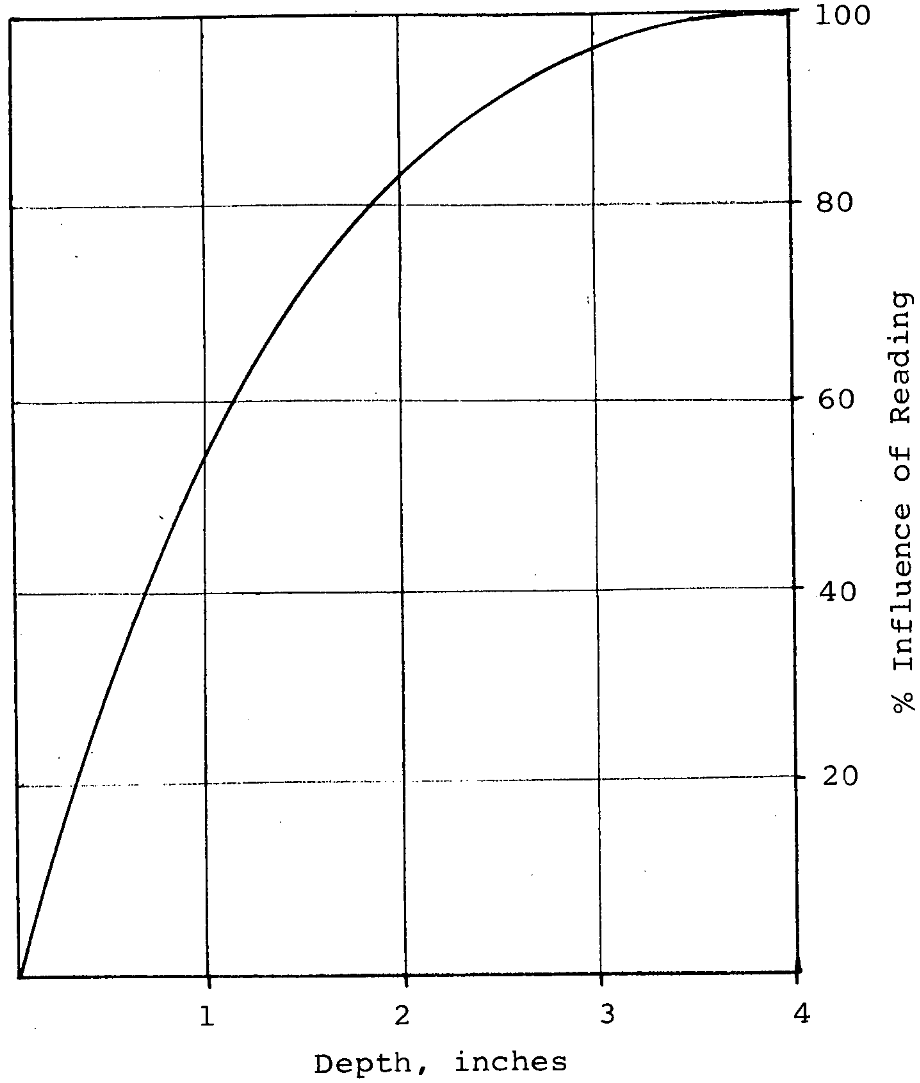
One disadvantage of nuclear backscatter monitoring with an air gap is that the influence of material density on indicated density is greatest at the surface and decreases rapidly with depth. Large voids as the result of poor consolidation could exist in the lower two-thirds of the pavement and may not even be detected by the CMD. For this reason, laboratory testing was done to determine the depth influence characteristics of the CMD.

To determine the amount of influence verses depth, a 15" x 15" x 2¼" (380 mm x 380 mm x 57mm) steel block was placed in the bottom of one of the molds and covered with concrete. CMD density readings were taken with a 4 inch (100 mm) concrete cover layer, a 3 inch (76 mm) layer, and a 2½ inch (64 mm) layer. Thinner layers of cover could not be recorded since the density reading was off the CMD scale. The density of the steel block was 458.6 lbs./cu.ft. (7340 kg/m^3) and the concrete had a density of 137.2 lbs./cu.ft. (2200 kg/m^3).

From the limited data obtained, a graph of depth influence was plotted. (See Figure 1) It is recommended more research be done in this area.

Figure 1

DEPTH OF INFLUENCE



<u>Calibration of the Troxler Moisture/Density Gauge</u>

As part of the evaluation of the CMD, comparisons between a Troxler gauge and the CMD readings were made. In order to insure an accurate comparison, the Troxler gauge was calibrated with the weighed density of the 2 cubic foot (0.056 m^3) molds.

Troxler - Weighed Density Calibration

	Troxler lbs./cu.ft.	Weighed Density lbs./cu.ft.
Mix A	141.5 140.5	136.2
Mix B	151.5 151.5	149.8
Mix C	143.0 143.5	140.6
Mix D	148.5 149.0	147.9
Mix E	148.5 146.0	146.0

A calibration factor of -2.2 lbs./cu.ft. was obtained to adjust the Troxler readout to correct density for the plastic concrete.

FIELD EVALUATION

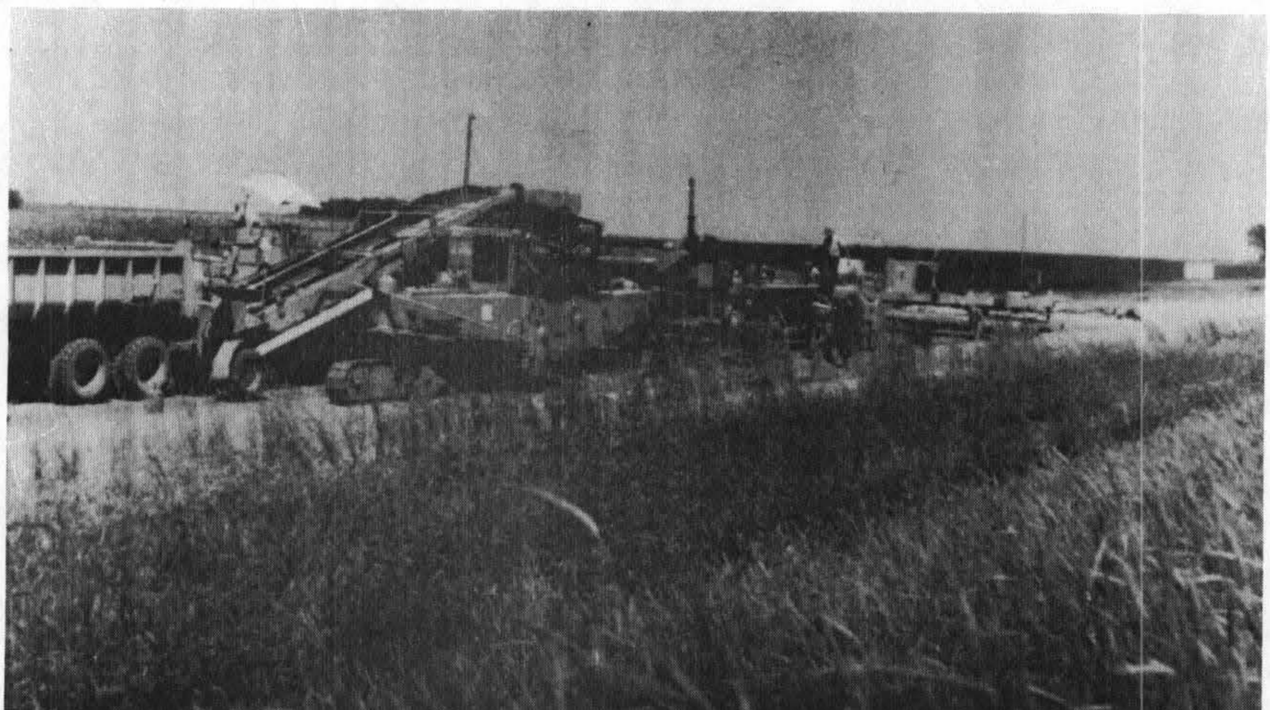


Photo 8
Audubon Slip Form Paving Operation

Preparations for the field evaluation of the CMD began with the mounting of the traverse beam and carriage. The contractor (Fred Carlson Company) had considerable difficulty mounting the equipment since the adjustable supports were developed for a different model slip-form paver. The assistance of someone with previous CMD experience would have been very beneficial. As it was, the mounting was a trial-and-error process and several angle-iron mounts were fabricated to adapt the adjustable supports to fit the Rex STR paver. The final mounting was not perfect, but the contractor did an admirable job of getting everything in workable order.

Phillip Lee, Research Engineer for Rexnord, Inc., assisted in the final stages of installation and provided valuable assistance in familiarizing the Iowa DOT personnel with the field operation of the CMD.

Project Mix Design

As stated earlier, the field construction materials are the same as those used in the laboratory calibrations. The coarse aggregate is a crushed limestone and the fine aggregate is a concrete sand.

FIELD MIX DESIGN

Mix No. C-6

Volume	27 cu.ft.	
Cement	676 lbs.	
Aggregates	Fine	Coarse
cu.ft.	10.376	6.872
Specific Gravity	2.67	2.65
Dry Batch Weights	1729 lbs.	1136 lbs.

Unit Absolute Volume Proportions

Cement	.127782 cu.ft.
Water	.173371
Air	.060000
Fine Aggregate	.384308
Coarse Aggregate	.254539
	1.000000 cu.ft.

Note: 1 lb. = .454 kg; 1 cu.ft. = 0.028 m^3

Operating Procedure

Field evaluation of the CMD began on June 14, 1978 on the Audubon RF-44-3(6) project. the First two days of monitoring were spent mainly on getting acquainted with the operating techniques. In its present state-of-art, the CMD is a very tedious machine to operate and requires considerable manual input. The employment of two persons on the project would have made the CMD easier and much safer to operate and is therefore recommended in future field evaluation.

After becoming familiar with the daily morning setup and calibration, the CMD could be readily installed in 30 minutes. Morning setup included installation of the control and readout unit, source, signal cables and sensor. The daily calibration consisted of adjusting the CMD to the laboratory established values for the magnesium/aluminum block and steel insert. On most mornings, very little adjustment of the CMD calibration was necessary. The traverse beam was let down once paving operations were resumed each morning. The 1 in. (25.4 mm) air gap was set and concrete density monitoring commenced (Photo 9). The air gap was checked approximately twice each hour and each time there were changes in the crown on the road. Maintaining a 1 inch (25.4 mm) air gap proved to be the most difficult variable to minimize on the CMD. The opinion of the research investigators is that if the air gap cannot be more precisely maintained or automatically compensated for, it will be difficult to get a reliable evaluation of the CMD and the consolidation of the pavement.

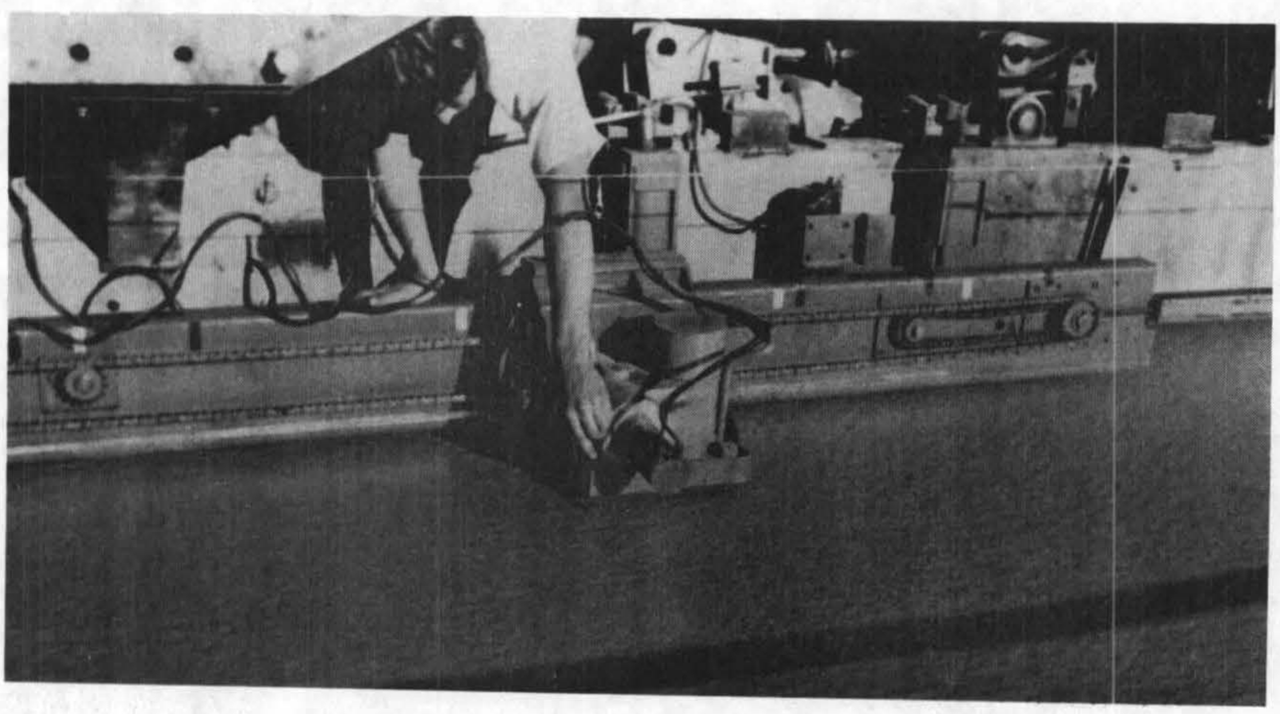


Photo 9
The CMD held stationary for monitoring and adjusting the air gap.

At the end of each day of monitoring, the control and readout unit, source, signal cables, and sensor were removed. Also the traverse beam was raised up so as to be out of the contractors way as far as possible.

Vibrator Study

The Iowa DOT Work Plan called for a special vibrator study to be conducted. The study was to determine if one type of vibration was consolidating the concrete more uniformly and with a greater density. The study consisted of determining concrete densities using 3 different vibrating efforts; 1) pan vibrator, 2) prod vibrators, 3) combination of both the pan and prod vibrators. Due to the limited capabilities of the paver, an effort to determine the effect of varying the frequency and/or magnitude of vibration on the density could not be made.

The contractor preferred to use the pan vibrator over the prods because of less concrete build-up ahead of the extrusion arm. Therefore, most of the CMD field monitoring was conducted on concrete which was pan vibrated. The CMD readout indicated the pan vibrator provided uniform consolidation and no unusual characterisitics. During the 5 miles (8.05 km) of monitoring, the density measured by the CMD ranged from an average low of about 138 lbs./cu.ft. (2210 kg/m^3) to a high of 144 lbs./cu.ft. (2300 kg/m^3). This 6 lbs./cu.ft. (100 kg/m^3) spread in high and low densities was considered to be insignificant for 1½ months of paving. It should be noted here that the 138-144 lbs./cu.ft. (2210 - 2300 kg/m^3) range is within the high-low calibration. The monitoring done with the prod vibrator in operation revealed that a slight variance in densities occurs at and between the prods. A drop of about 1 to 3 lbs./cu.ft. (16-48 kg/m^3) was noted between the prods. The prods were spaced from 18 inches (460 mm) to 30 inches (760 mm) apart. More CMD data on the prod vibrators would have been helpful, but mechanical problems with the prods limited their use to a bare minimum.

A section was monitored with both the pan and prod vibrators. This combination did not appear to have advantages over using the pan or prods only. A slightly higher density could be detected at the prods, but the patter was not well-defined.

Construction Testing Comparison

Where possible, construction test results were related to a CMD density (Appendix D). The CMD densities were compared to unit weights as determined in a 0.25 cu.ft. air meter base. The coefficient of correlation for this comparison on a straight-line basis was -0.343. There is no significant correlation.

A linear correlation of the CMD densities and air content yielded a correlation coefficient of -0.045. Again there is no significant correlation.

Core Drilling Correlation

In accordance with the Work Plan, approximately 10 coring locations per mile (68 cores) were selected. The 68 cores were then tested in the laboratory for density, strength and air content. The CMD density reading at each location was recorded and compared to the top 4-inch (100 mm) wet core density determined by normal laboratory procedures (Appendix E). Since the CMD mainly monitors to a depth of 4 inches (100 mm) or less, the cores were sawed in two, with the top 4 inches (100 mm) density in the comparison. The standard error of the mean in densities between the CMD density and the density of the top 4 inches (100 mm) of the wet cores is 2.52 lbs./cu.ft. (72 kg/m^3). The coefficient of correlation is 0.0543, which also indicates there is not a significant relationship between the two densities. Although these values are very sensitive to the CMD readings at core location where spikes occured in the strip chart trace, these low readings cannot be disregarded.

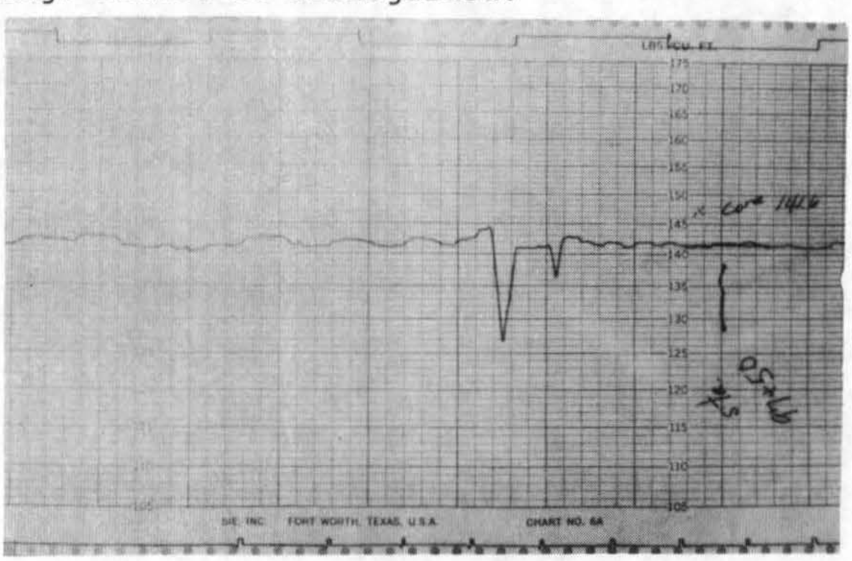


Photo 10
Trace displaying "Spikes"

It is the investigators opinion that these critical points of low density readings are the places where an inspector should be concerned. From all indications, these "spikes" are a result of an electrical failure within the CMD and not improperly consolidated concrete. Therefore, the cause of the randomly occurring "spikes" must be determined before the CMD is a trustworthy instrument.

When the standard error of the mean and coefficient of correlation are calculated with the low CMD "spike" readings omitted, the correlation is still not good. A standard error of 2.00 lbs./cu.ft. (32 kg/m^3) and a coefficient of 0.3605 still exists.

CMD - Troxler Correlation

A density correlation on 10 location between the CMD and a conventional Troxler nuclear gauge was calculated. The following is the data used:

CMD lbs./cu.ft.	Troxler lbs./cu.ft.
140.5	144.3
142.0	142.3
142.5	142.3
142.8	143.8
141.5	141.8
141.5	141.8
140.5	142.3
140.0	141.8
140.5	139.8
139.5	139.3

The standard error of the mean is 1.23 lbs./cu.ft. (20 kg/m^3) and the coefficient of correlation is 0.5241. The largest difference is densities between a pair of measurements is 3.8 lbs./cu.ft. (61 kg/m^3). This correlation with a conventional nuclear gauge is not as good as we had anticipated.

Hardened Versus Plastic Concrete CMD Correlation

Upon completion of the plastic concrete monitoring, the CMD was used to measure the density of the hardened concrete at several of the core locations. A correlation between the densities of the hardened and plastic concrete as measured by the CMD was determined.

Hardened Concrete lbs./cu.ft.	Plastic Concrete lbs./cu.ft.
141.0	141.3
142.3	141.7
141.0	140.2
142.5	140.2
142.8	141.3
144.0	142.6
140.5	140.0
140.7	139.6
140.5	140.6
140.5	140.5
139.9	144.3
139.6	139.6
139.5	139.8
139.3	139.4

The standard error of the mean in densities between the two CMD readings is 1.25 lbs./cu.ft. (20 kg/m^3). The coefficient of correlation is 0.3758 which indicates poor correlation. Some variance in the hardened and plastic concrete readings can be expected due to the drying of the concrete, however, this would result in a lower density. By inspection of the above values, it can be seen that in most cases the CMD density for hardened concrete is monitored at equal or above the density of the plastic concrete. The conclusion is that the reproducibility of the CMD readings is very inadequate under field conditions.

Conclusions from the Field Evaluation

CMD density measurements under field conditions appear less accurate than in the laboratory situation when compared to core densities. Speculation is that the density difference is primarily explained by the difficulty of maintaining the 1 inch (25.4 mm) air gap between the sensor head and the concrete surface. The research investigators believe some modification must be made to either measure the 1 inch (25.4 mm) air gap and compensate for the difference or to insure automatic control for the air gap. Also the nature of the "spikes" in the strip chart density trace must be determined and eliminated. The conclusion is that the CMD will not be a dependable instrument until these modifications are made. Field testing also proved to everyone involved that the unit is difficult to handle, however, the heavy shielding does protect the operators from detrimental radiation exposure. Until the operating ease is improved, the CMD will not be a practical instrument either.

ACKNOWLEDGEMENTS

We wish to express our appreciation to Rick Carlson, Norman Larson and others of the Fred Carlsons Company for the excellent cooperation during the field evaluation.

We appreciate the Iowa DOT Denison Resident Construction personnel assistance during construction and the assistance of the District 4 Materials personnel in obtaining the cores.

REFERENCES

1. Lee, Phillip & Eggert, Glenn J., "Development of a Device for Continuous Automatic Monitoring of Consolidation of Fresh Concrete" Federal Highway Administration Report No. FHWA-RD-78-27 (March 1978)

APPENDIX

CALIBRATION

General

There are two types of calibration procedures required for the CMD and there are two other procedures that can be classified as periodic adjustments. The first calibration procedure uses fresh concrete for reference densities and is designed to negate possible effects of chemical composition of the concrete mix on the CMD density readings. The second calibration, which uses the magnesium/aluminum calibration block and a steel calibration sheet, is designed to correct for day-to-day variations in electrical circuit characteristics.

Calibration on Fresh Concrete

This procedure is similar to Federal Highway Administration Rapid Test Procedure RT-13[1]. Fresh concrete is placed in molds, its density is determined by measuring weight and volume, and the CMD is adjusted (calibrated) to indicate a concrete density equal to the calculated density of the concrete in the molds. The procedure is as follows:

1. Prepare at least three 2 ft x 2 ft x 6 inch molds (610 mm x 610 mm x 150 mm). Clean, seal, and determine their volume by filling with water and weighing. Weigh each mold empty and record the tare weight of each.

2. Mix concrete with 0, i.e., as low as possible, 5, and 10 percent entrained air and place in molds #1, #2, and #3, respectively. As a minimum, these three batches of concrete should be checked for unit weight (rodded or vibrated), slump, and entrained air. The mix design should be as close as possible to that which is expected to be encountered in the field.

3. Consolidate the concrete in the molds with a small hand-held vibrator, taking care to achieve uniform consolidation throughout the mold. Vibration at five locations--center and 8 1/2 inches (215 mm) in towards the center from each of the four corner--has been found acceptable.

4. Strike-off and finish the concrete surface to a level as close as possible to the top edge of the molds, thus insuring a volume of concrete equivalent to the water-level-full volume used to calculate mold volume.

5. Treat the concrete surface to prevent loss of moisture.

[1]FHWA Notice N5080.17, June 17, 1974.

6. Weigh the molds, subtract the tare weight of each mold, and divide by the volume of each mold to establish a "weighed density" of the concrete for each of the three air contents.

7. Assemble and warm up CMD. Install sensor assembly and source holder into source/sensor unit, connect cables, turn on CMD power by moving switch first to RESET then to ON. Place OPERATE/CALIBRATE switch in OPERATE position and CAL HI/OFF/CAL LO switch in OFF position. Set TIME CONSTANT switch to 5 seconds. Turn on chart paper drive.

8. Place the source/sensor unit in the calibration frame and place entire assembly on one of the fresh concrete molds (Figure 30). Adjust vertical position so that source/sensor unit is 1 ± 1/16 inch (25 ± 2mm) off of concrete surface. Check all 4 corners. Verify that this gap exists with each of the three molds.

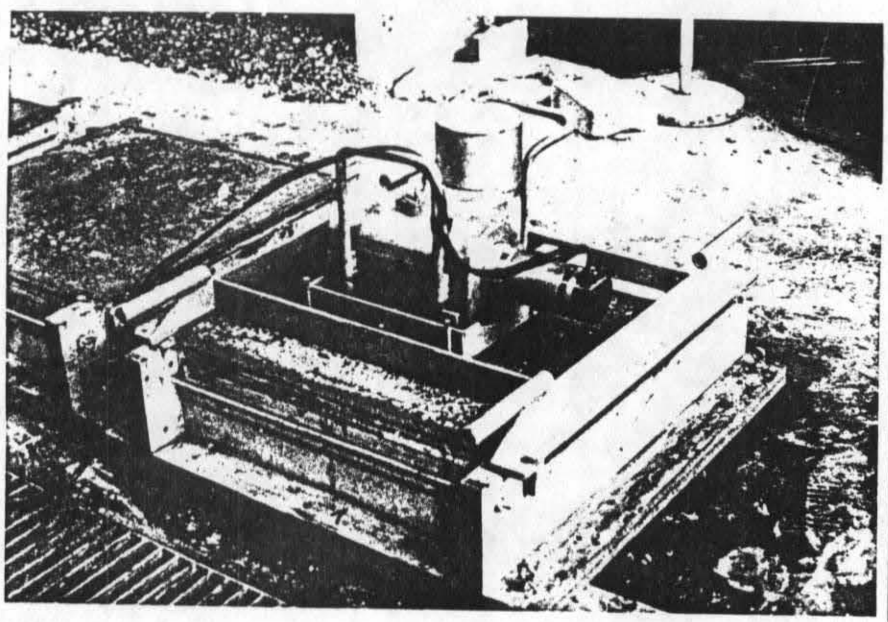


Fig. 30--Source/Sensor Unit in Calibration Frame, Placed on Concrete Mold

9. Alternately place the source/sensor unit (with calibration frame) on molds #1 and #3 (0 and 10 percent air respectively) and adjust the ZERO and SPAN adjustments of the density readout meter until the meter indicates densities equal to the weighed densities as determined in step (6) above. When making readings, allow at least 15 seconds for the density to stabilize.

10. Place the source/sensor unit on mold #2 (5 percent air) and compare the weighed density of this mold with the CMD density measurement.

11. The chart recorder can now be adjusted to follow exactly the density indicated on the density readout meter. The first step in this process is to adjust the HI and LO calibration potentiometer. Move the OPERATE/CALIBRATE switch to CALIBRATE, and the CAL HI/OFF/CAL LO switch to CAL HI. Adjust the recessed HI potentiometer with a small screw driver until the density readout meter indicates the higher weighed density value. Likewise, with the switch CAL LO position, adjust the LO potentiometer until the meter reads the low weighed density value.

12. Now, alternately switch the CAL HI/OFF/CAL LO switch from CAL HI to CAL LO and adjust the chart recorder ZERO and SPAN potentiometers until the recorder indicates the density of two weighed densities respectively. For increased accuracy, visually average a trace of at least 6 inches (150 mm) of chart paper.

13. Place the source/sensor unit (without calibration frame) on the calibration block. For best results, the calibration block should be located on a concrete, gravel, or soil surface (Figure 31). With the steel calibration sheet in place on top of the

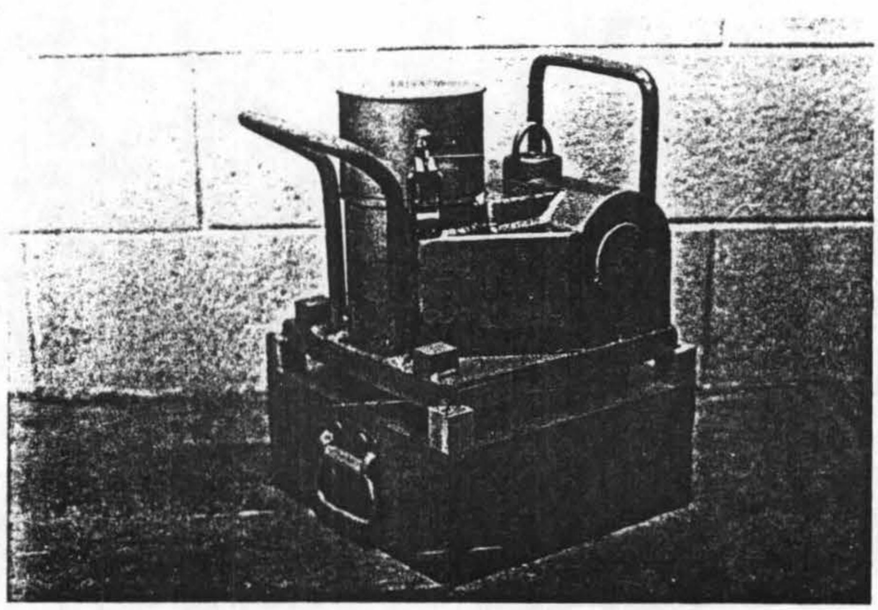


Fig. 31--CMD on Calibration Block

block, record the density reading from the chart recorder. Call this value D_1. Likewise, with the sheet removed, record the CMD density reading and call this value D_2. Henceforth, these two density readings are to be used whenever the CMD is to be calibrated to monitor density of concrete having the same or similar mix design.

14. Below is shown the mix design and calibration block readings obtained during the development phase of this instrument and can be used as an initial guideline for other mixes. With more experience with other mixes, the calibration procedure on fresh concrete may become unnecessary.

Mix Design:
- Wisconsin Highway Department - 3500 psi (24.1 MPa) at 28 days
- mixture of three type 1 portland cements
- natural sand fine aggregate
- 3/4-inch (19 mm) max. size coarse calcareous aggregate
- neutralized Vinsol resin air entraining admixture

Calibration Reading: D_1 (with steel sheet) = 149.0 pcf (2387 kg/m^3)

D_2 (without steel sheet) = 129.5 pcf (2075 kg/m^3)

Calibration on the Calibration Block

This process requires the calibration block density readings that were previously established by calibration on fresh concrete. Two density values are required--one for the block with the steel calibration sheet (D_1) and one without the sheet (D_2). The procedure is as follows:

1. Assemble and warm up the CMD. Install the sensor assembly and the source holder into the source/sensor unit, connect cables, turn on the CMD power by moving switch first to RESET, then to ON. Place OPERATE/CALIBRATE switch in OPERATE position and CAL HI/OFF/CAL LO switch in OFF position. Set TIME CONSTANT switch to 5 seconds. Turn on chart paper drive.

2. Place the source/sensor unit on the calibration block (Figure 31)

Searle Diagnostics Inc.

Health Physics Services
Box 1387, Oakton Street Station
Des Plaines, Illinois 60018
Phone Toll Free (800) 323-6015
In Illinois Collect (312) 635-3387
Telex 72-6443

Radiation Exposure Report

Form No. SD-S1-1

Seal of Approval

To:
IOWA STATE HWY COMM
MATERIALS LABORATORY
826 LINCOLNWAY
AMES IA 50010

Shipped To:
IOWA STATE HWY COMM
AMES STOREROOM
826 LINCOLNWAY
PO # A - 1970
AMES IA 50010

Customer Number	Report Printed	Notification Level	Freq.	Standard Exposure Period
23695	07/29/78		1	1 MONTH

Process Number	Film Received
683	07/14/78

Important
See reverse side for complete explanation of report data.

When making inquiries about this exposure report, refer to the customer and process number.

Badge #	Type	Name	Social Security Number	Current Monitoring Period: Start Date (Badge Date)	Note	X - G	Beta	Fast Neutron	Whole Body (7+9)	Skin (7+8+9)	Quarter to Date: Whole Body	Skin	# PDS	Year to Date: Whole Body	Skin	Life-Time Whole Body	Unused Permissible Dose	Birth Date and Sex	Service Start Date
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
001	14			06/01/78	R						0	0	2	18	18	628			03/30/71
001	14			06/01/78	R						0	0	2	18	18	328			03/30/71
002	14			06/01/78	R						[illegible]	0	2	46	46	586			03/30/71
002	14			06/01/78	R						0	0	2	46	46	585			03/30/71
003	14			06/01/78		45	0	0	45	45	121	121	3	135	135	1352			03/30/71
004	14			06/01/78		44	0	0	44	44	128	128	4	128	128	583			03/30/71
005	14			06/01/78		32	0	0	32	32	75	76	3	76	76	400			03/30/71
006	14			06/01/78		0	0	0	0	0	0	0	3	20	20	762			03/30/71
061	14			06/01/78		15	0	0	15	15	15	15	3	15	15	15			04/02/78
062	14			06/01/78		25	0	0	25	25	45	46	3	46	46	45			04/02/78
063	14			06/01/78		0	0	0	0	0	30	30	3	30	30	30			04/02/78
064	14			06/01/78		12	0	0	12	12	12	12	3	12	12	12			04/02/78
065	14	V. Marks		06/01/78		0-	0	0	0	0	22	22	3	22	22	22			04/02/78
066	14	R. Less		06/01/78		0-	0	0	0	0	18	18	3	18	18	18			04/02/78
067	14	R. Smith		06/01/78		0-	0	0	0	0	21	21	3	21	21	21			04/02/78
068	14			06/01/78		42	0	0	42	42	79	79	3	79	79	79			04/02/78
069	14			06/01/78		36	0	0	36	36	57	57	3	57	57	57			04/02/78
070	14			06/01/78		0	0	0	0	0	22	22	3	22	22	22			04/02/78
071	14			06/01/78		0	0	0	0	0	19	19	3	19	19	19			04/02/78
072	14			06/01/78		0	0	0	0	0	41	41	3	41	41	41			04/02/78
073	14			06/01/78		23	0	0	23	23	57	57	3	57	57	57			04/02/78
074	14			06/01/78		0	0	0	0	0	17	17	3	17	17	17			04/02/78
075	14			06/01/78		0	0	0	0	0	17	17	3	17	17	17			04/02/78
076	14			06/01/78		0	0	0	0	0	18	18	3	18	18	18			04/02/78
077	14			06/01/78		0	0	0	0	0	0	0	3	0	0	0			04/02/78
078	14			06/01/78		0	0	0	0	0	15	15	3	15	15	15			04/02/78
079	14			06/01/78		0	0	0	0	0	13	13	3	13	13	13			04/02/78
080	14			06/01/78		13	0	0	13	13	13	13	3	13	13	13			04/02/78
081	14			06/01/78		0	0	0	0	0	0	0	3	0	0	0			04/02/78
082	14			06/01/78		0	0	0	0	0	51	51	3	51	51	51			04/02/78
083	14			06/01/78		19	0	0	19	19	48	48	3	48	48	48			04/02/78
084	14			06/01/78		0	0	0	0	0	0	0	2	0	0	0			04/02/78
085	14			06/01/78		0	0	0	0	0	0	0	2	0	0	0			04/02/78
086	14			06/01/78		17	0	0	17	17	35	35	3	35	35	35			04/02/78
087	14			06/01/78		0	0	0	0	0	13	13	3	13	13	13			04/02/78

1— X,B,G Clip-on 5— Extended Range X,B,G
2— X,B,G Wrist 14— X,B,G, & N Clip-on
3— X,B,G Ring 24— X,B,G, & N Wrist

Please keep this Report for your records

33

APPENDIX B

Form No. SD-51-1

Searle Diagnostics Inc.

Health Physics Services
Box 1367, Oakton Street Station
Des Plaines, Illinois 60018
Phone Toll Free (800) 323-6015
In Illinois Collect (312) 635-3387
Telex 72-6443

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826 LINCOLNWAY
PO # A - 1970
AMES IA 50010

Customer Number	Report Printed	Notification Level	Freq.	Standard Exposure Period
23695	08/30/78		1	1 MONTH

Process Number	Film Received	
710	08/17/78	Important See reverse side for complete explanation of report data.

When making inquiries about this exposure report, refer to the customer and process number.

Badge #	Type	Name	Social Security Number	Current Monitoring Period: Start Date (Badge Date)	Note	X - G	Beta	Fast Neutron	Whole Body (7+9)	Skin (7+8+9)	Quarter to Date: Whole Body	Skin	# RDS	Year to Date: Whole Body	Skin	Life-Time Whole Body	Unused Permissible Dose	Birth Date and Sex	Service Start Date
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
001	12			07/01/78		0	0	0	0	0	0	0	1	18	18	828			03/30/71
002	12			07/01/78		0	0	0	0	0	0	0	1	46	46	586			03/30/71
003	12			07/01/78		29	0	0	29	29	29	29	1	164	164	1381			03/30/71
004	12			07/01/78		13	0	0	13	13	13	13	1	141	141	601			03/30/71
005	12			07/01/78		0	0	0	0	0	0	0	1	76	76	403			03/30/71
006	12			07/01/78	1			0	0	0	0	0	1	20	20	762			03/30/71
061	12			07/01/78		11	0	0	11	11	11	11	1	26	26	26			04/02/78
062	12			07/01/78		0	0	0	0	0	0	0	1	46	46	46			04/02/78
063	12			07/01/78		10	0	0	10	10	10	10	1	40	40	40			04/02/78
064	12			07/01/78		0	0	40	40	40	40	40	1	52	52	52			04/02/78
065	12	V. Marks		07/01/78		0	0	0	0	0	0	0	1	22	22	22			04/02/78
066	12	R. Less		07/01/78		0	0	0	0	0	0	0	1	18	18	18			04/02/78
067	12	R. Smith		07/01/78		0	0	0	0	0	0	0	1	21	21	21			04/02/78
068	12			07/01/78		26	0	0	26	26	26	26	1	105	105	105			04/02/78
069	12			07/01/78		11	0	0	11	11	11	11	1	68	68	68			04/02/78
070	12			07/01/78	4			0	0	0	0	0	1	22	22	22			04/02/78
071	12			07/01/78		0	0	0	0	0	0	0	1	19	19	19			04/02/78
072	12			07/01/78		0	0	0	0	0	0	0	1	41	41	41			04/02/78
073	12			07/01/78		0	0	0	0	0	0	0	1	57	57	57			04/02/78
074	12			07/01/78	4			0	0	0	0	0	1	17	17	17			04/02/78
075	12			07/01/78		0	0	0	0	0	0	0	1	17	17	17			04/02/78
076	12			07/01/78		0	0	0	0	0	0	0	1	18	18	18			04/02/78
077	12			07/01/78		215	0	0	215	215	215	215	1	215	215	215			04/02/78
078	12			07/01/78		0	0	0	0	0	0	0	1	15	15	15			04/02/78
079	12			07/01/78		0	0	0	0	0	0	0	1	13	13	13			04/02/78
080	12			07/01/78		0	0	0	0	0	0	0	1	13	13	13			04/02/78
081	12			07/01/78		0	0	0	0	0	0	0	1	0	0	0			04/02/78
082	12			07/01/78		0	0	0	0	0	0	0	1	51	51	51			04/02/78
083	12			07/01/78		12	0	0	12	12	12	12	1	60	60	60			04/02/78
084	12			07/01/78		22	0	0	22	22	22	22	1	22	22	22			04/02/78
085	12			07/01/78		13	0	0	13	13	13	13	1	13	13	13			04/02/78
086	12			07/01/78		0	0	0	0	0	0	0	1	35	35	35			04/02/78
087	12			07/01/78		0	0	0	0	0	0	0	1	13	13	13			04/02/78
088	12			07/01/78		11	0	0	11	11	11	11	1	66	66	65			04/02/78
089	12			07/01/78		35	0	0	35	35	35	35	1	53	53	53			04/02/78

1— X,B,G Clip-on 5— Extended Range X,B,G
X,B,G Clip-on
3— X,B,G Ring 2— X,B,G & N Wrist
XXXXXXXXXXXXXXXXXXXXXXXXX

Please keep this Report for your records

LABORATORY CALIBRATION DATA

Volume of Molds

Mold	Gross lbs.	Tare lbs.	Net lbs.	Volume cu.ft.
#1	173.15	47.45	125.70	2.015
#2	173.25	47.80	125.45	2.011
#3	174.60	48.10	126.50	2.028
#4	175.90	49.50	126.40	2.026

CONCRETE MIX DESIGN

Materials	Mix A	Mix B
Cement	60.09 lbs.	56.34 lbs.
Water	25.97 lbs.	24.34 lbs.
Air agent, CSC	-	23.04 units
Fine Aggregate	152.51 lbs.	142.98 lbs.
Coarse Aggregate	101.02 lbs.	94.71 lbs.

Cement: Ash Grove
Fine Aggregate: Brayton, Iowa SW 25-78-36
Coarse Aggregate: Menlo, Iowa SE 17-77-31

CALIBRATION SAMPLES

MIX A

Slump:	3½"
Air:	11.2%
Unit Weight:	132.86 lbs/cu.ft.
Gross Weight:	319.3 lbs.
Tare:	44.9 lbs.
Net:	274.4 lbs.
Volume:	2.015 cu.ft.
Density:	136.2 lbs/cu.ft.

MIX B

Slump:	2"
Air:	3.5%
Unit Weight:	147.28 lbs/cu.ft.
Gross Weight:	350.7 lbs.
Tare:	47.2 lbs.
Net:	303.5 lbs.
Volume:	2.026 cu.ft.
Density:	149.8 lbs/cu.ft.

CONSTRUCTION TESTING SUMMARY

Field: Slump, Air, Unit Weight and Flexural Strength

Sta.	Slump	Air	Unit Wt. lbs/cu.ft.	Mod. of Rupture	CMD Density lbs/cu.ft.
166+25	1 1/2"	6.5%	142.0	735 psi	139.5
80+50	1 1/2"	5.5	143.0	950	141.0
37+75	2"	6.4	142.0	888	141.5
18+00	-	6.8	142.0	-	141.5
8+50	1 1/2"	6.5	139.6	862	142.0
420+00	1 1/2"	6.5	141.6	-	141.0
393+25	1 3/4"	6.8	139.6	877	140.5
381+10	1 1/2"	6.4	141.6	816	139.0
345+00	-	6.5	140.8	-	141.0
365+00	-	6.5	142.4	-	139.0
371+50	-	6.4	142.4	-	139.0
433+50	-	6.8	140.8	-	140.0

CORE DATA SUMMARY

Station	Core Density Top 4" (lbs/cu.ft.)	Core Density Bottom (lbs/cu.ft.)	Core Strength	Core Air Top 4"	Core Air Bottom	CMD Density
65+00	140.4	139.8	5185 psi	8.0%	8.3%	141.0
69+75	141.0	141.6	4840	7.4	6.9	140.0
75+62	141.0	141.6	4895	7.7	7.1	125.0
76+50	141.7	142.9	4845	6.8	6.0	142.0
81+00	140.4	141.0	4550	7.7	6.8	141.0
83+35	141.0	141.6	5160	7.7	6.5	141.5
86+00	141.7	141.6	4780	7.2	6.8	141.5
90+00	139.8	141.6	4520	7.5	6.5	140.5
93+00	140.4	141.0	4415	6.9	7.2	140.5
97+50	140.4	141.0	4175	8.2	6.6	142.0
103+48	141.7	141.0	4695	6.4	6.7	136.0
106+40	141.7	142.9	4700	6.5	5.8	142.8
108+92	140.4	141.0	4545	7.1	6.6	143.0
113+04	141.0	141.0	4585	6.9	6.7	142.5
138+17	140.4	140.4	3970	8.0	7.5	125.0
141+45	142.3	144.1	4765	6.9	5.5	142.5
147+75	141.7	141.6	4220	6.4	6.3	142.0
148+08	140.4	142.3	4775	7.2	6.5	142.5
155+06	140.4	141.0	4685	8.0	7.8	137.0
160+65	142.9	143.5	4110	5.7	5.6	142.5
161+30	139.8	141.0	3455	8.2	7.0	140.5
357+45	140.4	139.8	4295	7.3	7.6	138.0
363+50	139.8	139.8	4585	8.1	7.4	140.0
368+50	141.0	141.0	4615	7.6	6.9	140.0
371+56	140.4	141.6	4195	7.6	6.3	140.5
375+00	139.8	139.2	3565	8.2	7.9	140.0
380+47	139.8	139.8	4300	8.4	8.4	130.0
381+50	139.2	139.8	4040	8.5	8.0	139.0
384+50	141.7	141.6	4820	6.5	6.0	141.0
386+50	139.8	139.8	4520	7.6	7.5	141.0
390+50	139.8	140.4	4340	7.6	7.4	141.0
395+00	139.2	140.4	3580	7.9	7.8	140.5
400+50	140.4	140.4	4735	7.1	8.5	143.5
404+50	140.4	140.4	4645	7.6	8.3	140.5
408+50	139.8	140.4	4250	8.9	7.5	141.0
412+50	140.4	141.0	4810	8.0	8.6	142.0
417+00	141.0	139.8	4525	7.1	8.4	141.0
10+00	140.4	142.3	5030	7.9	6.2	142.0
14+00	139.8	141.6	4440	8.0	6.3	139.5
17+50	140.4	141.6	4645	7.5	8.1	141.5
20+50	141.7	142.9	5070	7.1	6.6	141.0
23+50	139.8	141.6	4475	7.7	8.3	140.0
27+00	141.0	140.4	4515	6.9	8.8	144.5
29+50	141.7	140.4	4800	6.8	10.2	141.5
33+00	139.2	138.5	3915	8.2	10.4	139.0
36+00	139.8	141.0	4670	8.4	8.0	141.5
40+50	141.0	142.9	4930	7.0	6.4	143.5
44+50	139.2	140.4	4565	8.4	7.1	143.5
46+00	141.7	142.9	4710	7.1	7.4	141.5
325+50	140.4	142.4	4240	7.4	7.2	139.5
329+35	141.0	142.3	4855	7.2	7.6	136.0
332+62	142.3	139.8	4575	6.0	7.9	121.0
336+42	139.8	139.8	3890	7.7	8.1	131.0
338+85	140.4	141.0	4295	9.0	7.9	140.0
356+40	136.7	138.5	3950	7.9	9.3	136.0
358+90	140.4	140.4	4340	7.4	7.3	126.0
362+00	141.7	140.4	--	6.7	7.8	141.0
365+50	139.8	141.0	5105	8.3	8.0	138.0
366+50	141.0	141.6	4605	7.4	7.8	140.5
369+00	140.4	141.0	4690	7.5	7.8	139.0
372+00	140.4	141.6	4740	7.8	7.7	139.0
427+50	140.4	141.0	4605	8.0	8.5	140.0
431+50	139.8	131.0	3970	8.0	7.4	141.5
435+00	138.5	139.8	3730	8.0	9.3	139.5
438+50	139.2	139.8	4405	8.1	9.0	140.0
452+50	141.0	140.4	4390	6.7	8.0	142.5
457+50	141.7	141.6	4635	6.5	7.7	142.5
462+50	141.0	139.8	3885	7.3	8.8	140.5