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# FIELD TRIAL OF CONTINUOUS ASPHALT CONCRETE DENSITY MONITORING DEVICES - FINAL REPORT

MICHIGAN
DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

TE270 .D3 c.1 c. 4
Field trial of continuous asphalt concrete density monitoring devices-final report

# FIELD TRIAL OF CONTINUOUS ASPHALT CONCRETE DENSITY MONITORING DEVICES - FINAL REPORT

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Research Project 83 D-45
Research Report R-1242

Lansing, March 1984

# INTRODUCTION

An evaluation of two nuclear asphalt monitoring devices was conducted by the Research Laboratory under FHWA Basic Agreement DOT-FH-11-9211, Task Order No. 12. One device, the asphalt concrete density and temperature monitoring device (DMD) was a prototype constructed under contract for the FHWA and included an infrared temperature sensor along with a nuclear density gage (Fig. 1). The second device, also a roller-mounted unit (Fig. 2), is a commercially available compaction gage purchased by the FHWA for field evaluation. The second unit, called a DOR (density on the run),measures only density with no temperature sensing capability.

Under terms of the Task Order, the devices were evaluated in the laboratory as well as in the field. Laboratory tests were performed on blocks of known density to verify calibration of the devices and to determine the effective volume of material being tested.

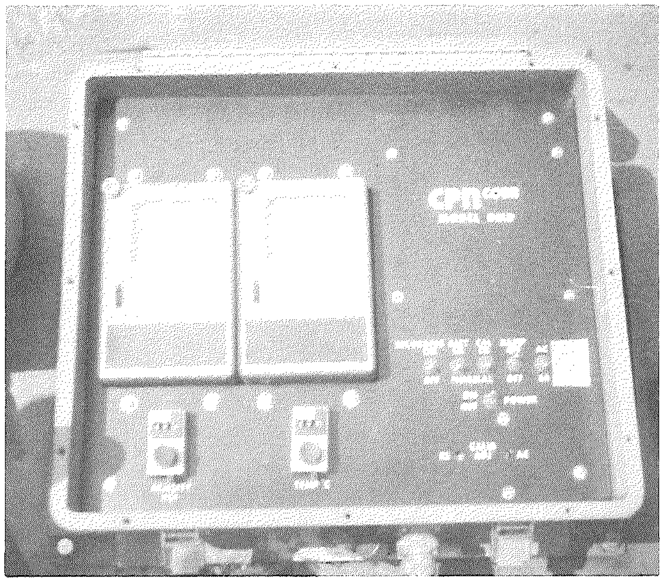
Field evaluation was conducted with the devices mounted on compaction rollers and involved comparisons with conventional nuclear gage values and core density results. Tests were conducted on a 6-in. thick lift and on a thinner, 1-in. lift.

# DESCRIPTION OF EQUIPMENT

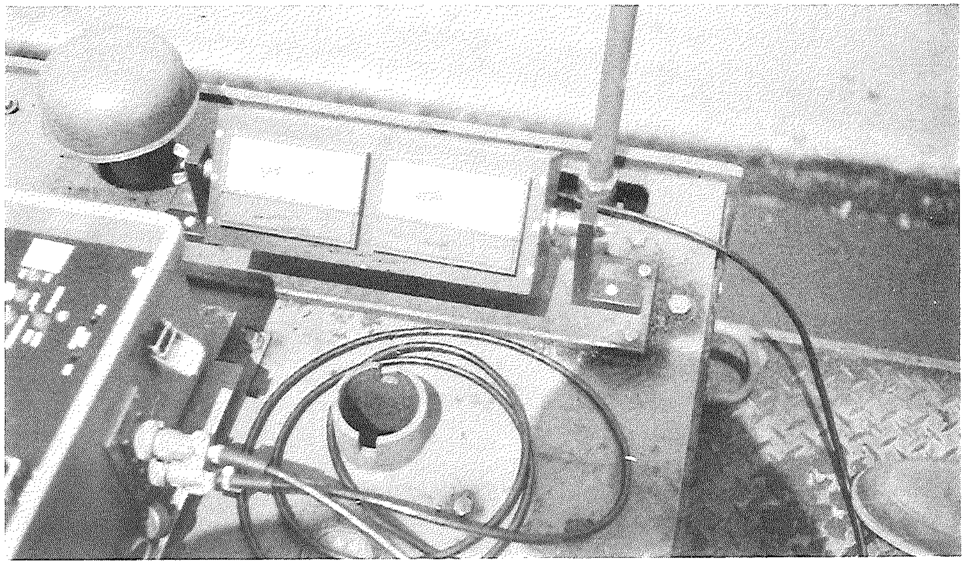
The two devices are both backscatter-type nuclear density gages similar in operating principles to the gages used for many years for soil density measurements. Despite the similarity in basic design, there are several mechanical and operational features which are different, and which are of importance when evaluating the usefulness and applicability to bituminous compaction operations.

The DMD device consists of three instrument components, plus a reference standard, and measures both the density and temperature of the bituminous layer (Fig. 1). The density and temperature sensing unit, mounted in front of the roller on a suspension frame, slides along (and contacts) the paved surface. Readout units consist of a pair of meters along with a strip-chart recorder mounted in the control unit; the meters provide the roller operator with visual information regarding mat compaction and temperature, while the recorders provide permanent copies of the data. Layers of various thicknesses are measured for density by changing the position of the radioactive source within the DMD sensing head. The DMD source rod handle has two operating positions, as seen in Figure 3; one for measuring layers from 1.4 to 2 in. thick ('thin lift' or TL), and one for greater thicknesses (Full Depth or FD). A switch in the control unit must also be set to correspond with the source rod setting, either TL or FD, to obtain proper readings.

DMD sensing unit mounted on front of roller.

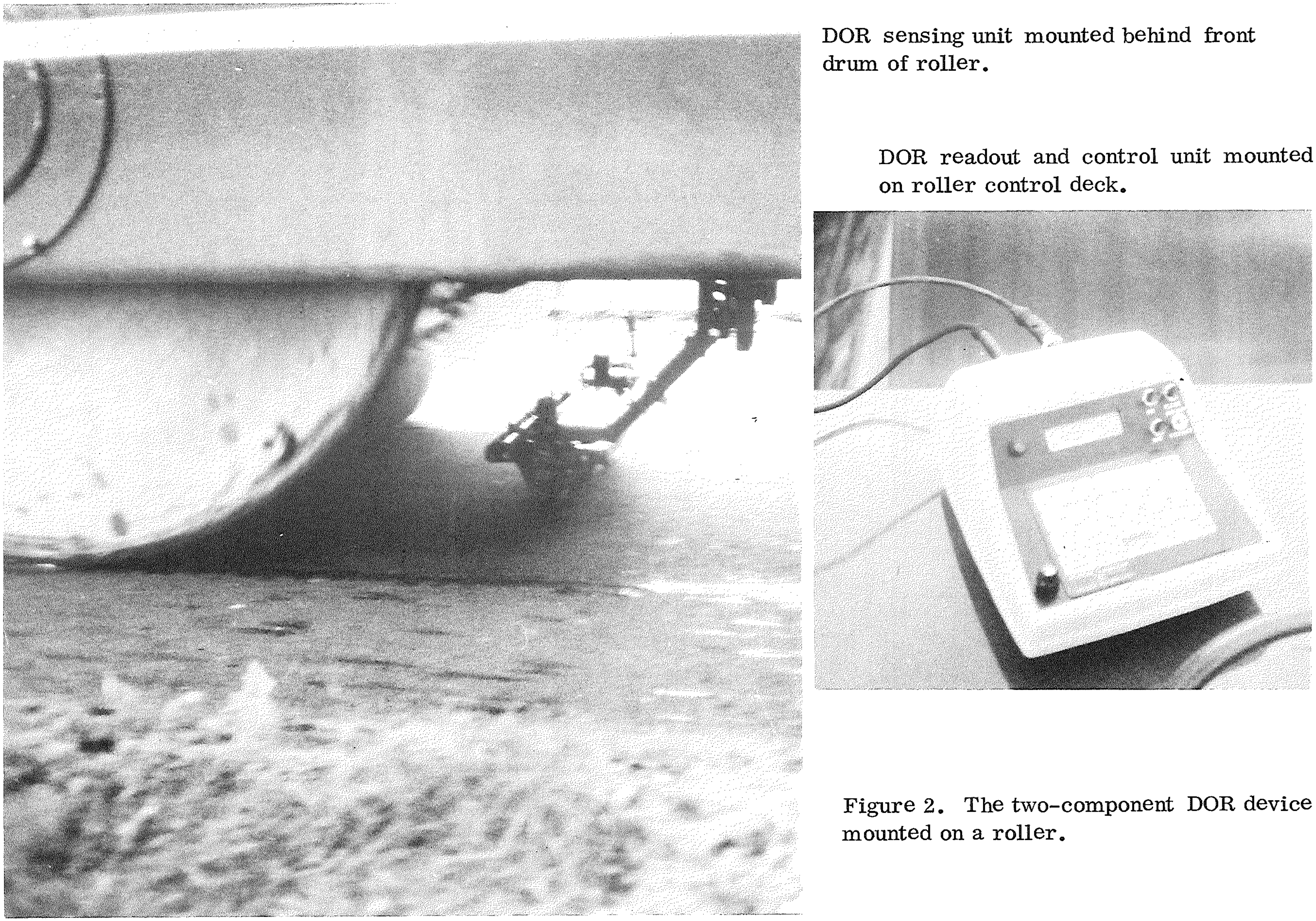


DMD control unit with strip-chart recorders mounted on roller control deck.



DMD meter readout unit mounted on roller control deck.

Figure 1. The DMD device consists of three instrument components plus a reference standard block (not shown).



DOR sensing unit mounted behind front drum of roller.

DOR readout and control unit mounted on roller control deck.

Figure 2. The two-component DOR device mounted on a roller.

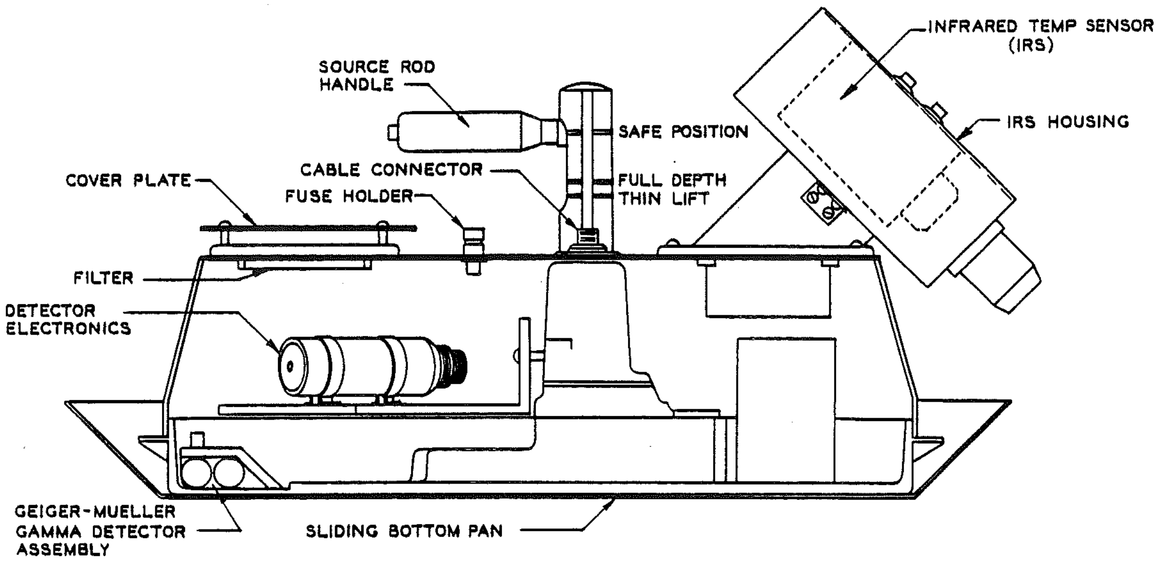


Figure 3. Sectional view of DMD sensing unit showing major components and source control rod positions.

The DOR unit consists of two components, the sensing unit and the control and readout unit (Fig. 2). The sensing unit, mounted under the compaction roller, immediately behind the front drum, rolls along the newly compacted surface. The sensing head is connected to a lift mechanism so that it can be raised by the roller operator, while moving, for travel over rough surfaces. Digital readout is displayed by the control unit which can be programmed to display either "Bulk Density" or "Per Cent Bulk Density" test results. The control unit can also be programmed to compensate for measurement of thin lifts by entering the thickness of the top lift and the density of the underlying material.

## EVALUATION PROCEDURE

Laboratory and field measurements were made with both devices in this evaluation. Laboratory evaluation involved the measurement of response on reference blocks of known density as well as the determination of the volume of material that each device measures.

Proper operation of the DMD device was checked by placing the sensing head on the calibration block supplied with the device. The device was calibrated in accordance with manufacturer's instruction for both the Full Depth and Thin Lift modes by setting the 133.6 pcf reference density value in the target density control display. After calibration on the reference block (which involved the entire device including the sensing head), the instrument calibration check was performed (with sensing head disconnected);

the instrument calibration check values listed in Table 1 were obtained in this manner throughout the study. After the initial instrument calibration in the laboratory no further adjustments were made; It was felt that recording of subsequent calibration check values without adjustment would provide a measure of long-term instrument stability not possible by adjustment.

TABLE 1
DENSITY CALIBRATION CHECK VALUES FOR
THE DMD NUCLEAR DENSITY DEVICE

| Date Checked | Instrument Calibration Check Values* | |
|---|---|---|
| | F.D. | T.L. |
| Per Operating Manual | 120.65 | 175.32 |
| 7-25-83 | 118.3 | 174.7 |
| 7-26-83 | 118.2 | 175.2 |
| 7-29-83 | 117.7 | 175.1 |
| 8-1-83 | 117.5 | 175.1 |
| 8-16-83 | 117.5 | 176.1 |
| 8-18-83 | 119.6 | --- |
| 8-19-83 | 111.7 | --- |
| 9-7-83 | 119.5 | 176.5 |

*Calibration standard value of 133.6 pcf was used for all calibration checks.

The air-gap method of density measurement used with the DOR provides the means for assuring proper functioning of the device. An air-gap reading must be obtained prior to density testing. New air-gap readings are taken whenever the device is started at the beginning of the day, at midday, and whenever a change in the chemical composition of the mix is suspected. These readings, though fluctuating due to the radioactive source, are reasonably consistent in value and can be used to assure proper functioning of the device. The air-gap readings obtained during the laboratory evaluation, Table 2, could, for example, be used in control chart form, as an instrument check during subsequent testing.

For field evaluation, each device was mounted on a steel drum roller and used in conjunction with the compaction of bituminous base and overlay mixtures. Static nuclear gage readings and core specimens were obtained for comparison with measurements made by the two devices. In all, seven test sections were involved with the DOR evaluated on four sections and the DMD on three sections (Fig. 4).

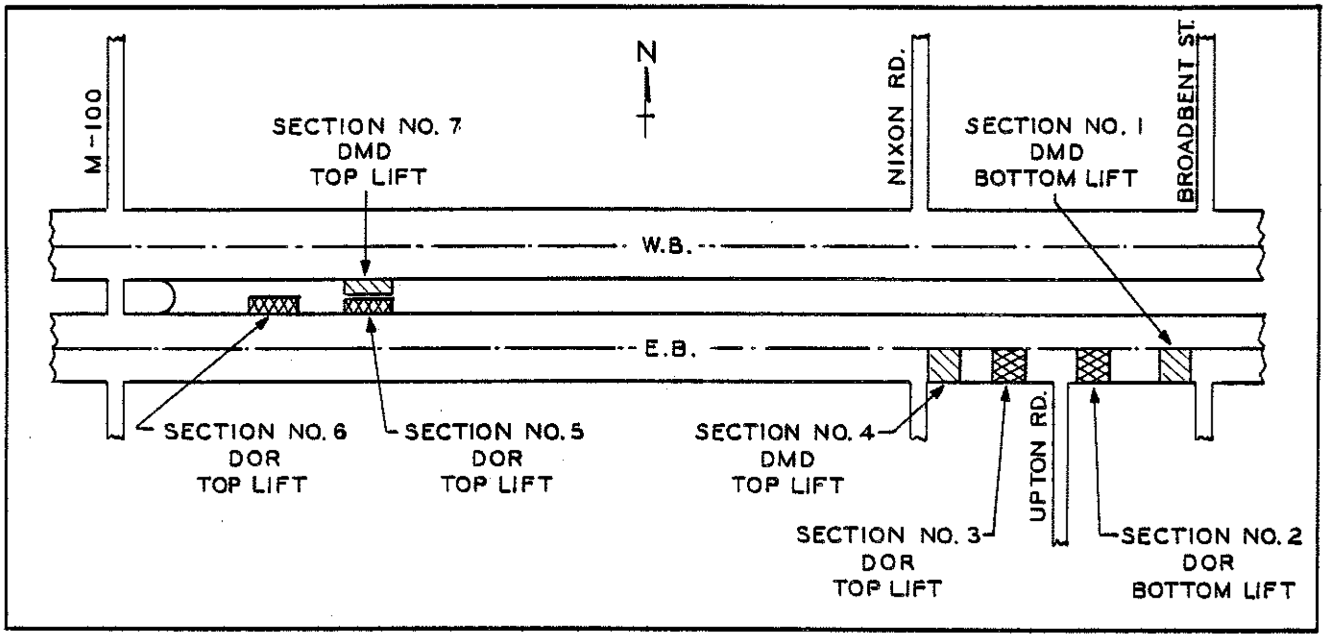
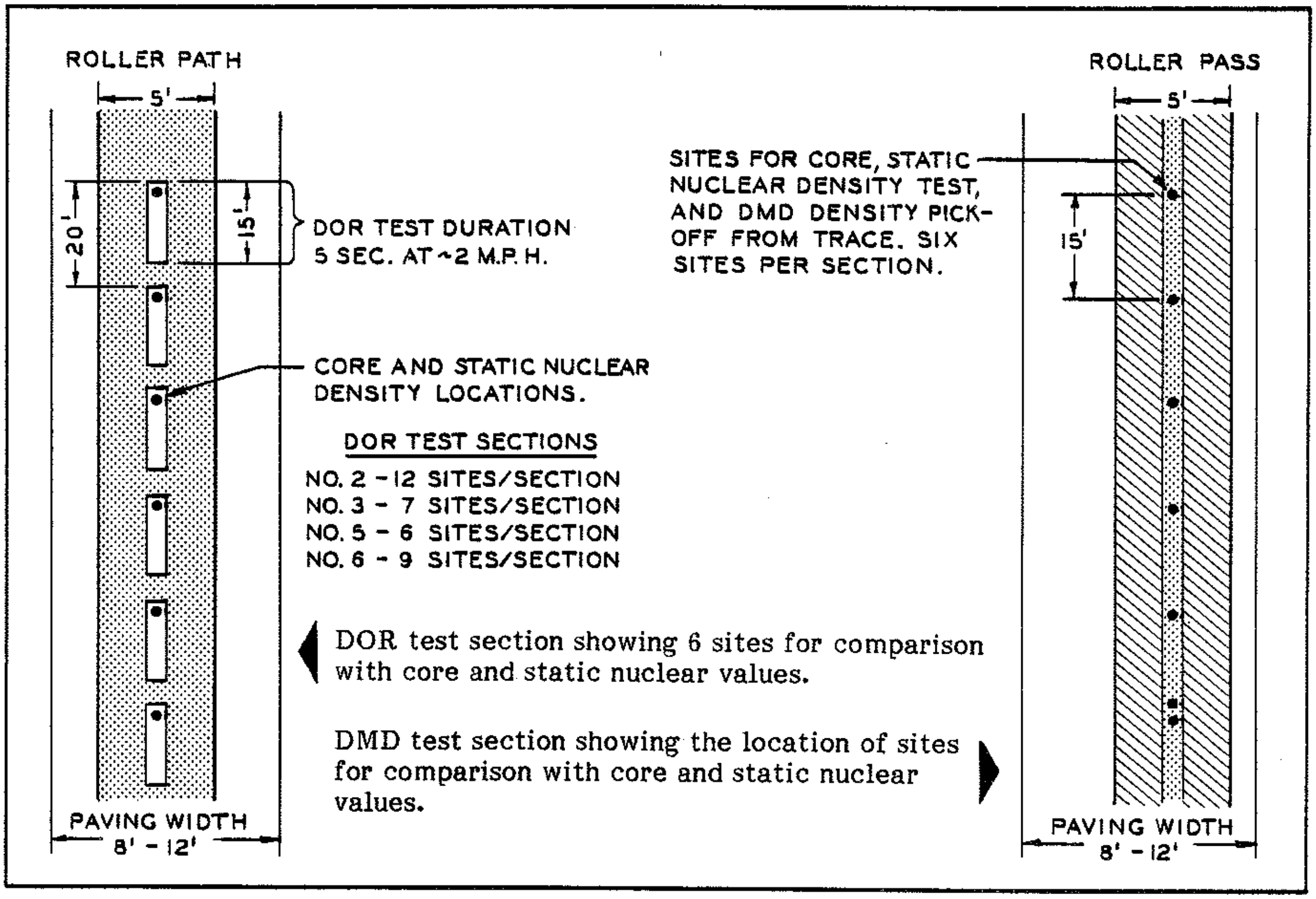


Figure 4. Location of DMD and DOR field evaluation test sections.



◀ DOR test section showing 6 sites for comparison with core and static nuclear values.

DMD test section showing the location of sites for comparison with core and static nuclear values. ▶

Figure 5. Typical DMD and DOR test sections showing locations of core samples and static nuclear density tests.

## TABLE 2
## SUMMARY OF LABORATORY MEASUREMENTS OBTAINED ON REFERENCE BLOCKS

| Reference Block | | Measured Density, pcf | | |
|---|---|---|---|---|
| | | | DMD | |
| Material Reference | Density, pcf | DOR | Full Depth | Thin Lift |
| Calibration Check | | --- | 118.3 | 174.7 |
| A. Magnesium | 110.1 | 109.5 | 107.4 | 104.9 |
| B Mag./Alum. Laminate | 138.6 | 136.4 | 134.6 | 132.1 |
| C. Limestone | 139.6 | 139.7 | 138.5 | 134.9 |
| D. Granite | 165.1 | 167.3 | 159.7 | 151.1 |
| E. Aluminum | 165.1 | 166.0 | 160.4 | 161.3 |
| Average Absolute Difference (Block Density - Nuclear Device Value) | | 1.18 | 3.58 | 6.84 |

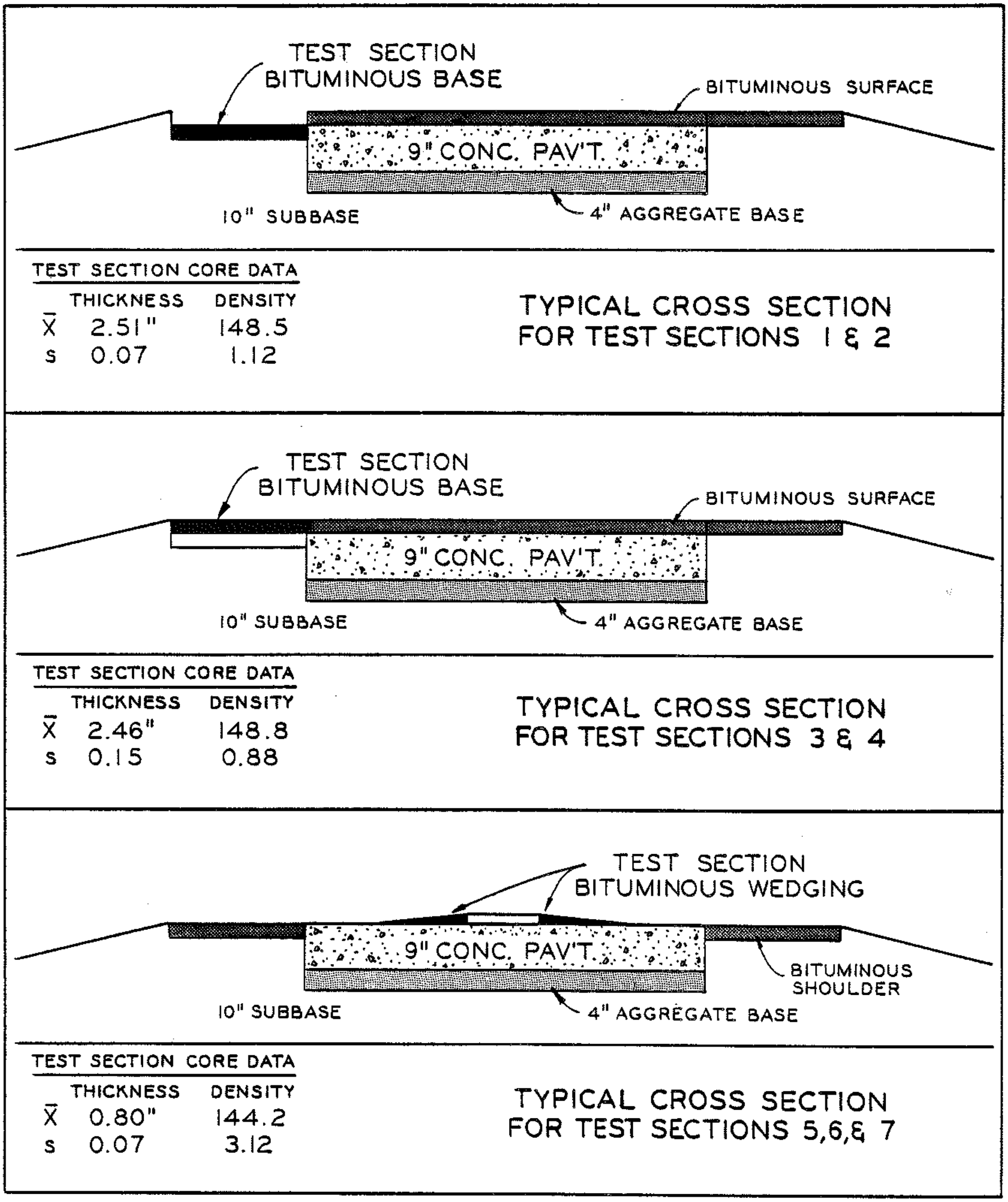
A typical test section is shown in Figure 5 which shows the location of DOR and DMD density readings, core locations and static nuclear gage test sites. Cross-sections showing layer thicknesses are shown in Figure 6. All DOR and DMD tests were performed while the roller was moving in accordance with the normal operation for which the units were designed.

Each unit was used on two base course test sections made with a Michigan 20-C bituminous mixture. The units were then evaluated on three test sections consisting of a Michigan No. 1100 leveling course mixture made with a 20AA aggregate; the DOR was used on two of these sections and the DMD on one.

Composition of the base course mixture was determined from extraction tests on core samples as follows:

| Sieve Size | Percent Passing |
|---|---|
| 3/4-in. | 100 |
| 1/2-in. | 100 |
| 3/8-in. | 84.5 |
| No. 8 | 47.2 |
| No. 30 | 22.0 |
| No. 200 | 3.4 |
| Percent Asphalt | 5.6 |

Marshall mix design data for the leveling course mixture are given in Table 3.



TEST SECTION CORE DATA

| | THICKNESS | DENSITY |
|---|---|---|
| $\bar{X}$ | 2.51" | 148.5 |
| s | 0.07 | 1.12 |

TYPICAL CROSS SECTION
FOR TEST SECTIONS 1 & 2

TEST SECTION CORE DATA

| | THICKNESS | DENSITY |
|---|---|---|
| $\bar{X}$ | 2.46" | 148.8 |
| s | 0.15 | 0.88 |

TYPICAL CROSS SECTION
FOR TEST SECTIONS 3 & 4

TEST SECTION CORE DATA

| | THICKNESS | DENSITY |
|---|---|---|
| $\bar{X}$ | 0.80" | 144.2 |
| s | 0.07 | 3.12 |

TYPICAL CROSS SECTION
FOR TEST SECTIONS 5,6,& 7

Figure 6. Typical cross sections showing layer thicknesses at the test section locations.

## TABLE 3
## MARSHALL MIX DESIGN DATA, SURFACING MIXTURE

Control Section: FU 23042 Job No.: 20134A Lab. No: 83 MD-141

Date Tested: 07/07/83 Bit. Mix No. 1100 T & L 4.00 1979 Std. Specs. Supp.

Materials Used

| Material | Type | Source | Sp. Gr. |
|---|---|---|---|
| Asphalt Cement | AC-5 | Amoco | 1.013 |
| Dense Graded | 20AA | Pit No. 33-9 | |

Marshall Test Results: (Compactive Effort 50 Blows)

| | | | |
|---|---|---|---|
| Actual S.G. | 2.440 | 2.449 | 2.444 |
| Theo Max SG | 2.570 | 2.537 | 2.505 |
| Air Voids, % | 5.07 | 3.50 | 2.44 |
| VFA, % | 68.6 | 78.6 | 85.6 |
| VMA, % | 16.1 | 16.3 | 16.9 |
| Stability, lb | 2029 | 1655 | 1300 |
| Flow, 0.01" | 8.8 | 13.0 | 19.5 |

Aggregate Gradation Calculated
Cumulative Percent Passing

| | |
|---|---|
| 3/4-inch | 100.0 |
| 1/2-inch | 96.1 |
| 3/8-inch | 88.7 |
| No. 4 | 68.6 |
| No. 8 | 50.7 |
| No. 30 | 26.8 |
| No. 200 | 6.2 |

Mixture Prop., %

| | | | |
|---|---|---|---|
| Asphalt | 4.6 | 5.3 | 6.0 |

Project Mix Design:

| | |
|---|---|
| Asphalt, % | 5.6 |
| P 8, % | 50.7 |
| P 200, % | 6.2 |
| Optimum Asphalt Content = | 5.59 |
| @Optimum Specific Gravity = | 2.448 |
| Stability = | 1506.00 |
| Air Voids = | 3.00 |
| V.M.A. = | 16.51 |
| Flow = | 15.42 |
| Voids Filled with Asphalt = | 81.83 |

Material Submitted from Spartan Asphalt Plant No. 440-6

## RESULTS

### Laboratory Evaluation

Measurements made on the five reference blocks are summarized in Table 2 and Figure 7 for both devices. Table 2 compares average density values measured by each device with the density of each reference block. DOR values ranged from 2.2 pcf higher than block densities to 2.2 pcf lower with an average absolute difference of 1.18 pcf. Differences measured with the DMD device (in the full-depth mode) ranged from 1.1 pcf to 5.4 pcf lower than block densities with an average absolute difference of 3.58 pcf. In the thin lift mode the differences ranged from 3.8 pcf to 14.0 pcf lower with an average absolute difference of 6.84 pcf.

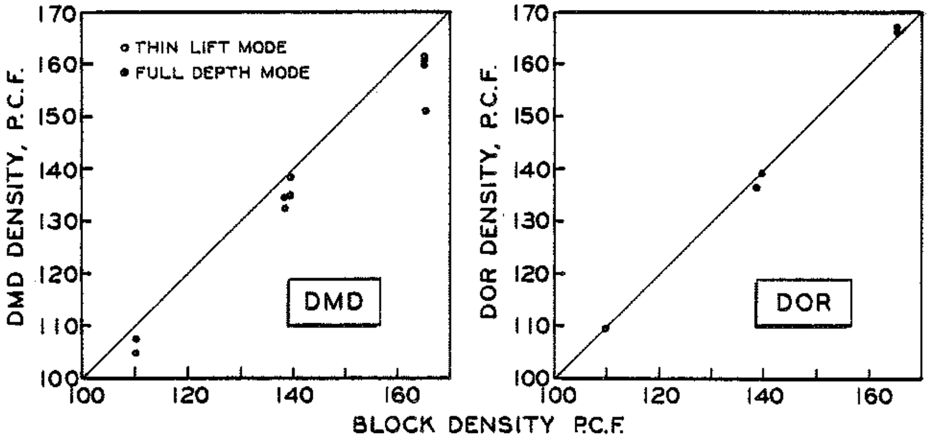


Figure 7. Relationship between reference block densities and densities measured with the two nuclear devices.

The precision, or repeatability, of the DOR device is presented in Table 4 for one-minute air-gap count readings and for one-minute, five-second, and three-second density test values. The standard deviation of the one-minute air-gap readings averages ±16.1 counts or, a coefficient of variation of 0.27 percent. Standard deviations for density values ranged from ±0.7 pcf for a one-minute test duration to ±3.2 pcf for a three-second test; respective variation coefficients were 0.51 percent and 2.21 percent. A 5 second interval was selected for the field evaluation to correspond with a 22-ft roller travel at 3 mph. This 22-ft distance allows for less chance of density variation than would longer sections corresponding to longer test times.

Precision of the DMD device must be estimated by reading a series of values from the chart recording such as that reproduced in Figure 8.

## TABLE 4
## SUMMARY OF DOR REPEATABILITY MEASUREMENTS AND LABORATORY REFERENCE SAMPLES

| Block | Air Gap Reading Count*/Std. Dev. 1 minute | Measured Density, pcf Density*/Std. Dev. | | |
|---|---|---|---|---|
| | | 1 minute | 5 seconds | 3 seconds |
| A. 110.1 | 5828/8.8 | 109.5/0.6 | 108.4/1.5 | 109.6/2.7 |
| B. 138.6 | 5945/17.7 | 136.4/0.6 | 136.3/1.8 | 136.2/1.7 |
| C. 139.6 | 5772/22.2 | 139.7/1.0 | 138.2/2.1 | 136.1/3.3 |
| D. 165.1 | 5982/22.6 | 167.3/0.8 | 167.1/3.9 | 167.8/4.0 |
| E. 165.1 | 5995/9.3 | 166.0/0.6 | 165.7/1.5 | 166.0/4.2 |
| Avg. Std. Dev. | 16.1 | 0.7 | 2.2 | 3.2 |

* Five readings, average and standard deviation.

The smallest vertical division represents 0.4 pcf with each 1 in. horizontal equaling 30 seconds (one mark per second). Duplicate readings on the reference blocks also provide an indication of the repeatability of the DMD device. In the full-depth mode, differences between the two readings averaged 0.86 pcf with a standard deviation of ±0.48 pcf; thin lift differences averaged 3.5 pcf with a standard deviation of ±4.39 pcf. Duplicate density values measured on the reference blocks are presented in Table 5, along with the differences between the two values. The readings in column "a", Table 5, were obtained for each block; the test was then immediately repeated on each of the blocks to obtain the values in columns "b".

Typical measurements of temperature recorded by the DMD are shown in Figure 9.

The thickness of material measured by each of the devices is represented by the results shown in Figures 10 and 11 for the DOR and the DMD, respectively. In this laboratory experiment 1-1/4-in. thick slabs of an asbestos-cement material (transite) were placed over granite and air substrates as shown in the figures. Density measurements were made with the nuclear devices for each increment of slab thickness. The asbestos-cement slabs were measured and weighed; the density was then calculated to be 121.4 pcf, approximately 20 pcf lighter than bituminous concrete.

Results shown in Figures 10 and 11 show that both units are influenced by a heavier granite substrate when the layer being tested is less than 2-1/2 in. in thickness. Substrates which are lighter than the material being tested can influence these devices when 4 in. or less in thickness. Although the granite and air substrates provide extreme density differentials the results do indicate that lift thicknesses and density differentials must be accounted

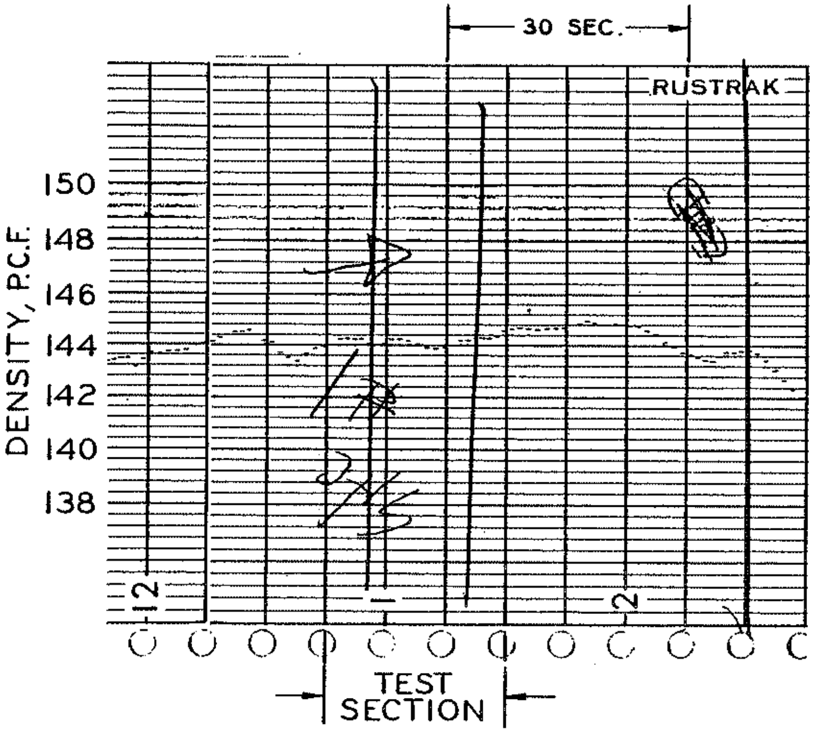


Figure 8. Recording of DMD density test values. One value recorded per second.

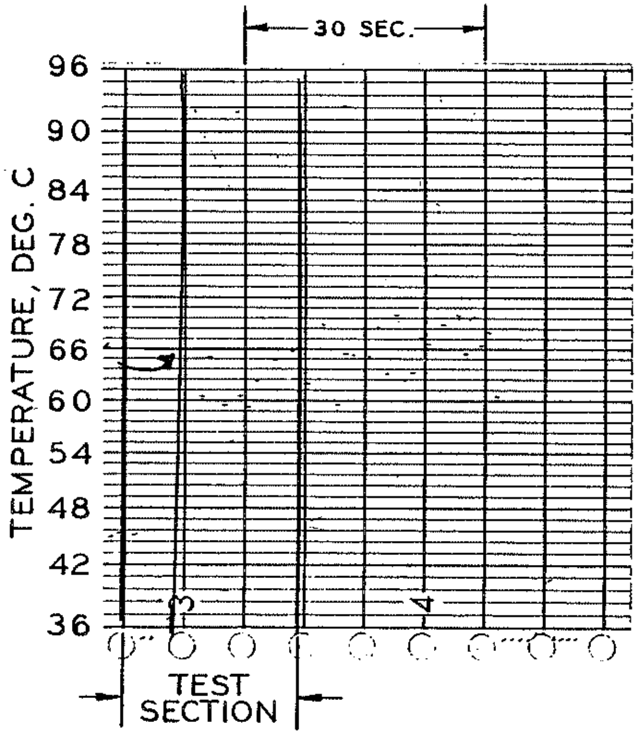


Figure 9. Infrared temperature measurements as recorded by the DMD device.

for, if possible, when using the devices on construction projects. Both units provide means for compensating for thin lifts and these methods were applied in carrying out the subsequent field evaluation.

TABLE 5
DUPLICATE DMD DENSITY MEASUREMENTS
ON LABORATORY REFERENCE BLOCKS

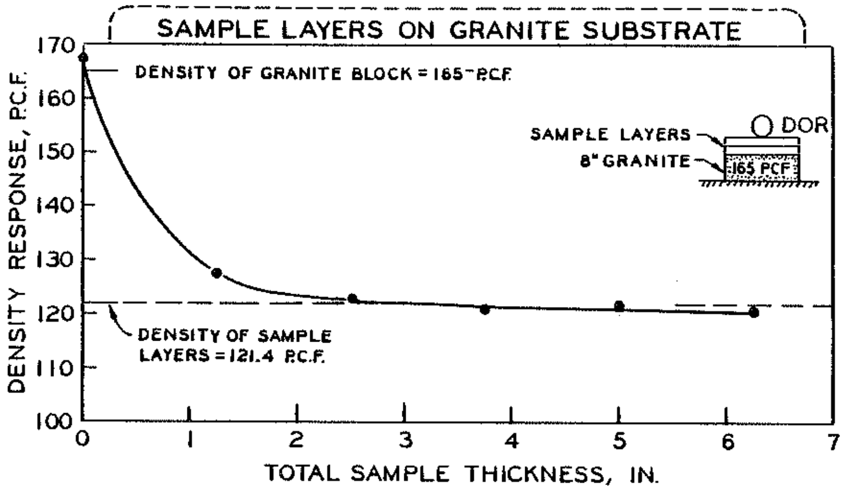
| Reference Block | Measured Density Values | | | | | |
|---|---|---|---|---|---|---|
| | Full Depth | | | Thin Lift | | |
| | Reading | | Difference | Reading | | Difference |
| | a | b | | a | b | |
| A 110.1 | 107.1 | 107.6 | 0.5 | 105.1 | 104.6 | 0.5 |
| B 138.6 | 134.0 | 135.1 | 1.1 | 127.8 | 136.3 | 8.5 |
| C 139.6 | 137.7 | 139.3 | 1.6 | 130.8 | 138.9 | 8.1 |
| D 165.1 | 160.0 | 159.4 | 0.6 | 151.1 | 151.0 | 0.1 |
| E 165.1 | 160.6 | 160.1 | 0.5 | 161.4 | 161.1 | 0.3 |
| Avg. Difference | | | 0.86 | | | 3.50 |
| Std. Deviation of Difference | | | 0.48 | | | 4.39 |

The lateral size of material influencing DOR readings is represented by the data shown in Figure 12. Material which is as far as 15 in. from the source is measured (orientation A). Material 5 to 10 in. from the source can influence DOR response in orientations B and C. Considering the combined results of orientation A and orientation B, the DOR seems to measure a sample 20 to 25 in. in width.

The response obtained with the DOR in orientation C indicates that a drop-off, pavement edge, or other discontinuity, can be approached to within 10 in. before density results are significantly influenced.

## Field Evaluation Results

The relationship between density values determined by the three methods, DMD, DOR, and core measurements, are summarized in Table 6; the table shows, for each test section, the average density, standard deviation, and number of test sites per section for each test method. The results presented in Table 6 are shown graphically in Figure 13. With the exception of Sections 4 and 5 the section average values obtained by the DMD and DOR agree closely with core density and static nuclear values. If the DMD average for Section 4 is adjusted in proportion to calibration check



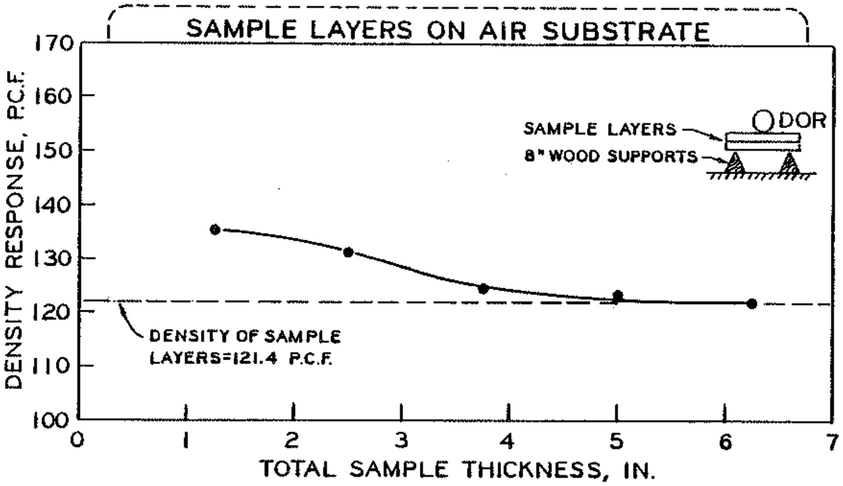
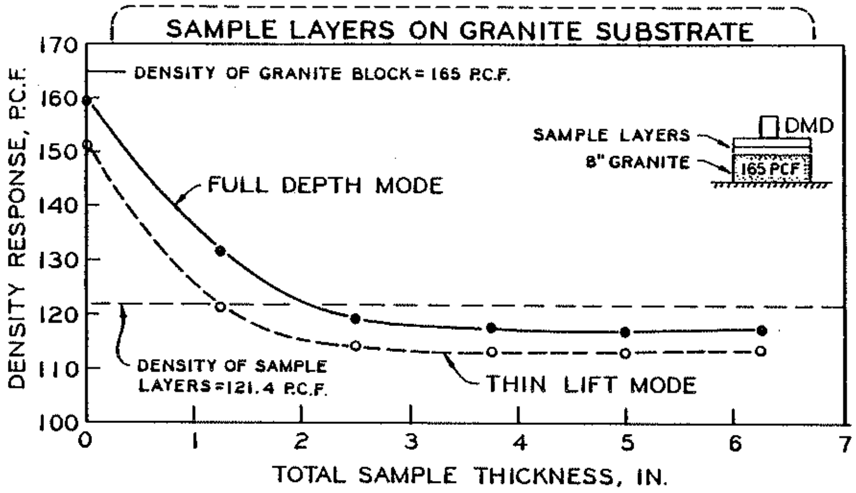


Figure 10. Relationship between DOR density response and thickness of material being measured as determined in the laboratory.



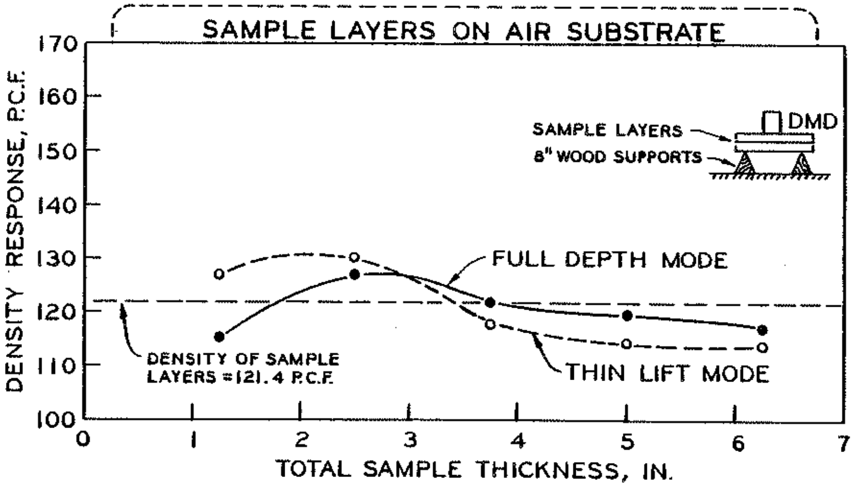


Figure 11. Relationship between DMD density response and thickness of material being measured as determined in the laboratory.

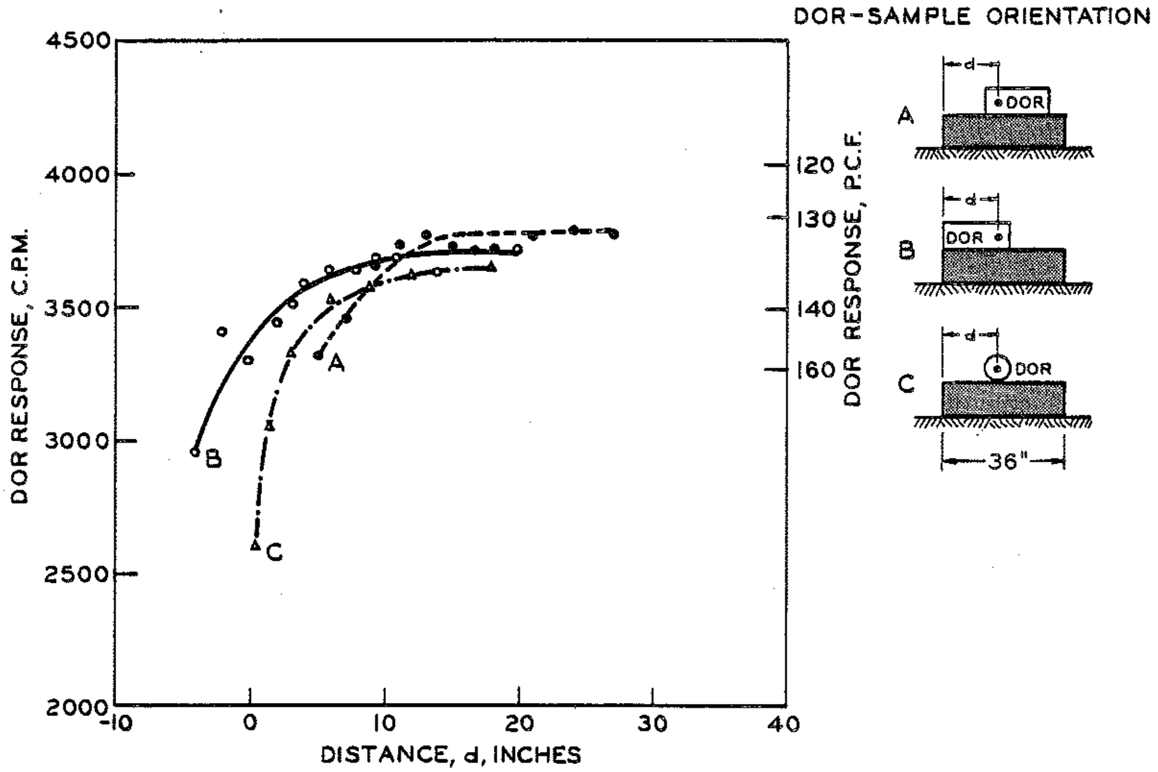


Figure 12. Relationship between DOR response and distance from edge of concrete block 40 by 36 in., by 10 in. thick.

values the average density would be 145.7 pcf making the comparison much better. Section 5 values, shown in Table 6 and Figure 13, involved only two DOR tests and one core measurement; results shown for this section should perhaps be omitted from the overall comparison.

As shown in the lower portion of Figure 13, DMD section averages ranged from 13.8 pcf less than, to 0.4 pcf more than core values, with an overall average of 6.1 pcf less. DOR values ranged from 2.8 pcf to 8.9 pcf less than core values with an overall average of 5.3 pcf less.

## DMD Temperature Measurements

Temperature values were recorded with the DMD device throughout the evaluation. Typical results are shown in Figure 9 for Section 1 which shows erratically varying values ranging from 40 C (113 F) to 66 C (151 F). Comparative measurements made with a hand held infrared temperature "gun" indicated the mix to be 82 C (180 F) with no noticeable variation within the test section. The erratic variation in DMD values, as shown in Figure 9, occurred throughout the study so no further evaluation of the temperature monitor was attempted.

## TABLE 6
## FIELD EVALUATION TEST RESULTS

| Section | | Test Method | | | |
|---|---|---|---|---|---|
| | | Nuclear Roller | Static Nuclear | | Core Sample |
| 1. F.D. (Cal. Check 119.6) | Avg. | 143.3 | 145.5 | | 148.2 |
| | Std. Dev. | 0.14 | 1.98 | | 1.00 |
| | No. Sites | 6 | 6 | | 6 |
| 4. F.D. (Cal. Check 111.7) | Avg. | 134.9 | 147.3 | | 148.7 |
| | Std. Dev. | 0.29 | 0.74 | | 0.87 |
| | No. Sites | 6 | 6 | | 6 |
| 7. T.L. (Cal. Check 176.5) | Avg. | 145.6 | 144.5 | | 145.2 |
| | Std. Dev. | 0.17 | 1.09 | | 2.02 |
| | No. Sites | 6 | 6 | | 6 |
| 2. F.D. Base, Bottom Course | Avg. | 145.8 | 148.4 | | 148.6 |
| | Std. Dev. | 4.12 | 1.18 | | 1.19 |
| | No. Sites | 12 | 12 | | 12 |
| 3. F.D. Base, Top Course | Avg. | 145.9 | 147.6 | | 148.9 |
| | Std. Dev. | 1.54 | 0.46 | | 0.95 |
| | No. Sites | 7 | 7 | | 7 |
| 5. T.L. Leveling | Avg. | 132.2 | 142.1 | 142.6 | 141.2 |
| | Std. Dev. | 1.48 | 0.14 | 0.93 | -- |
| | No. Sites | 2 | 2 | 6 | 1 |
| 6. T.L. Leveling | Avg. | 137.5 | 147.8 | | 143.9 |
| | Std. Dev. | 3.27 | 2.36 | | 3.79 |
| | No. Sites | 10 | 10 | | 8 |

T.L. - Denotes data obtained by operating the DMD in the thin lift mode as well as data obtained by the DOR and static nuclear after compensation for top lift thickness and base density.

F.D. - Denotes data obtained with the three nuclear devices when operating in the full depth or thickness mode.

- These values represent the entire test section whereas the other values for this section were obtained at two corresponding sites. See Table A2 in the Appendix for further clarification.

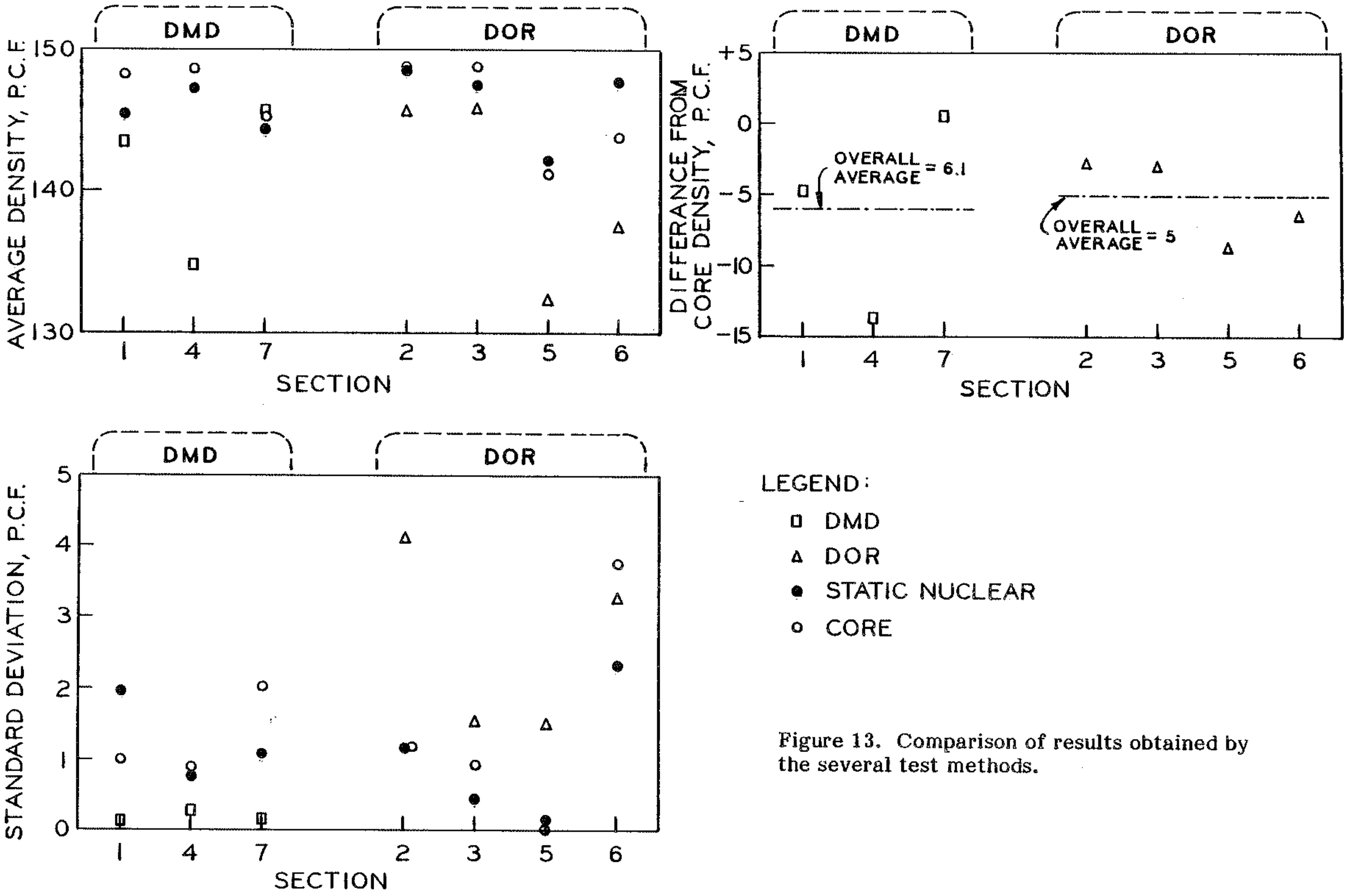


Figure 13. Comparison of results obtained by the several test methods.

# CONCLUSIONS

Laboratory tests show both devices can accurately and precisely measure density of materials. Accuracy of the DMD could probably be improved by calibration adjustment. Both devices, however, are influenced by material as much as two or more inches in thickness, as shown in the laboratory phase of the evaluation. Influence of material in a top layer of from 1/2 to 2 in. in thickness should be determined.

Field evaluation results provided reasonably good agreement with conventional measurements (core and static nuclear) for both devices. Core densities and static nuclear values were as scattered as the nuclear devices. The DMD field values had significantly lower variability than any other method.

Physical features of the two devices along with their operating features were an important part of this study. The DOR unit is the more convenient to use. It involves two basic pieces of equipment and provides clear, easily read results in digital form. Controls are similar to those common to desk-top electronic calculators and can be readily operated by anyone after a brief practice session. The DOR probe mounts under the compaction unit and is thus protected from obstructions such as curbs or abutments and can be raised by the roller operator while moving.

The DMD device is the more cumbersome of the two, involving three basic pieces of equipment. Readout is more difficult for an operator but a printed record is made as desired. The meter readout, of most value to the roller operator, provides a continually varying visual output; and, although the recorder prints a density value each second, the imprint is very small and faint and is obscured beneath the case of the recorder for several seconds. The DMD sensing head is mounted in front of the compaction roller where it could easily be pushed against a curb or other obstruction. It can be raised only when the roller is stopped and must be lifted by someone on the ground. Further, the sensing unit was not visible to the roller operator, thus compounding the likelihood of being damaged during operation.

Both devices can provide guidance to the roller operator in achieving adequate compaction; especially on layers two or more inches thick.

Both devices would seem to be useful to contractors on projects where density requirements are specified. Results obtained by the contractor would, however, provide only guidance with final approval based on tests performed by the Department. The devices, if owned by the contractor and mounted on his roller, would be of limited benefit to the Department.

Usefulness of devices such as the DMD and DOR to a highway agency depend on the type of compaction specification and timeliness of the agencies' measurements. With end result specifications the job, or subsections (inspection lots) of the job, are inspected after construction is completed. The material has by then cooled (temperature less than 170 to 200 F) so that no further compaction can be achieved and price adjustments are made in order to effectuate quality control. In this case the Department or highway agency would need an independent device (not roller mounted) for their inspections. This type of specification would promote the use of the roller mounted DMD or DOR units by contractors.

Most bituminous paving in Michigan involves the compaction of layers of less than 2 in. in thickness; to be useful to the Department, any density device should be able to accurately measure densities of layers in the 1 to 2-in. range without the influence of underlying layers. Both the DMD and DOR, however, are influenced by the density of underlying layers despite built-in corrective procedures.

# APPENDIX

# APPENDIX

Tabulations representing all data obtained during the field evaluation of the DMD and DOR devices.

Explanation of column desiginations:

T.L. - Denotes data obtained by operating the DMD in the Thin Lift mode as well as data obtained by the DOR and static nuclear after compensation for top lift thickness and base density.

F.D. - Denotes data obtained with the three nuclear devices when operating in their full-depth or thick lift modes.

Both F.D. and T.L. data are included for the static nuclear gage for the leveling course sections because F.D. values must first be recorded then corrected to yield T.L. values; correction involved the use of a graph supplied with the instrument so both sets of data were recorded by the operator.

## TABLE A1
## FIELD EVALUATION TEST Results, DMD

| Section No. | Site No. | Density Values | | |
|---|---|---|---|---|
| | | DMD F.D. | Static Nuclear F.D. | Core |
| 1<br>Base,<br>Bottom-<br>Course | 1 | 143.1 | 142.2 | 146.9 |
| | 2 | 143.3 | 144.7 | 147.9 |
| | 3 | 143.4 | 144.4 | 147.5 |
| | 4 | 143.3 | 147.6 | 148.4 |
| | 5 | 143.5 | 146.6 | 149.4 |
| | 6 | 143.2 | 146.7 | 149.3 |
| | Avg. | 143.3 | 145.5 | 148.2 |
| | Std. Dev. | 0.14 | 1.98 | 1.00 |
| 4<br>Base<br>Top Course | 1 | 135.1 | 146.4 | 147.4 |
| | 2 | 134.4 | 148.2 | 149.3 |
| | 3 | 134.7 | 146.4 | 148.9 |
| | 4 | 135.0 | 147.7 | 149.7 |
| | 5 | 135.2 | 147.6 | 149.0 |
| | 6 | 134.9 | 147.6 | 147.9 |
| | Avg. | 134.9 | 147.3 | 148.7 |
| | Std.Dev. | 0.29 | 0.74 | 0.87 |

## TABLE A1
## FIELD EVALUATION TEST RESULTS, DMD

| Section No. | Site No. | Density Values | | | |
|---|---|---|---|---|---|
| | | DMD T.L. | Static Nuclear | | Core |
| | | | T.L. | F.D. | |
| 7<br>Leveling | 1 | 145.6 | 144.4 | 147.2 | 141.7 |
| | 2 | 145.5 | 143.0 | 146.8 | 144.4 |
| | 3 | 145.5 | 146.1 | 148.0 | 145.1 |
| | 4 | 145.7 | 143.7 | 146.8 | 147.2 |
| | 5 | 145.9 | 144.9 | 147.2 | 145.6 |
| | 6 | 145.8 | 145.1 | 147.3 | 147.0 |
| | Avg. | 145.6 | 144.5 | 147.2 | 145.2 |
| | Std. Dev. | 0.17 | 1.09 | 0.44 | 2.02 |

## TABLE A2
## FIELD EVALUATION TEST RESULTS, DOR

| Section No. | Site No. | Density Values | | |
|---|---|---|---|---|
| | | DOR F.D. | Static Nuclear F.D. | Core |
| 2<br>Base,<br>Bottom<br>Course | 1 | 150.8 | 150.7 | 149.5 |
| | 2 | 145.7 | 149.7 | 150.2 |
| | 3 | 145.0 | 149.7 | 149.3 |
| | 4 | 144.4 | 148.2 | 149.6 |
| | 5 | 135.8 | 148.8 | 148.8 |
| | 6 | 144.1 | 148.1 | 148.3 |
| | 7 | 145.6 | 148.5 | 149.0 |
| | 8 | 146.0 | 148.4 | 148.8 |
| | 9 | 148.3 | 148.3 | 148.1 |
| | 10 | 149.8 | 147.6 | 145.6 |
| | 11 | 143.1 | 146.8 | 148.4 |
| | 12 | 151.0 | 146.6 | 147.5 |
| | Avg. | 145.8 | 148.4 | 148.6 |
| | Std.Dev. | 4.12 | 1.18 | 1.19 |

## TABLE A2
## FIELD EVALUATION TEST RESULTS, DOR

| Section No. | Site No. | Density Values | | |
|---|---|---|---|---|
| | | DOR F.D. | Static Nuclear F.D. | Core |
| 3<br>Base,<br>Top Course | 1 | 146.2 | 147.6 | 148.7 |
| | 2 | 146.3 | 147.3 | 148.3 |
| | 3 | 148.5 | 148.4 | 147.9 |
| | 4 | 144.7 | 147.1 | 148.3 |
| | 5 | 143.7 | 147.9 | 150.0 |
| | 6 | 145.3 | 147.2 | 150.4 |
| | 7 | 146.6 | 147.4 | 148.4 |
| | Avg. | 145.9 | 147.6 | 148.9 |
| | Std. Dev. | 1.54 | 0.46 | 0.95 |

## TABLE A2
## FIELD EVALUATION TEST RESULTS, DOR

| Section No. | Site No. | Density Values | | | | Core |
|---|---|---|---|---|---|---|
| | | DOR | | Static Nuclear | | |
| | | T.L. | F.D. | T.L. | F.D. | |
| 5<br>Leveling | 1 | * | 141.1 | 143.2 | 148.0 | |
| | 2 | * | 140.8 | 141.3 | 147.2 | |
| | 3 | 133.2 | 140.2 | 142.0 | 147.4 | 141.2 |
| | 4 | * | 141.1 | 142.8 | 147.8 | |
| | 5 | * | 139.2 | 143.9 | 148.2 | |
| | 6 | 131.1 | 138.9 | 142.2 | 147.5 | |
| | Avg. | 132.2 | 140.2 | 142.6 | 147.7 | |
| | Std. Dev. | 1.48 | 0.97 | 0.93 | 0.38 | |

* Operator error, only F.D. values were recorded.

## TABLE A2
## FIELD EVALUATION TEST RESULTS, DOR

| Section No. | Site No. | Density Values | | | | |
|---|---|---|---|---|---|---|
| | | DOR | | Static Nuclear | | Core |
| | | T.L. | F.D. | T.L. | F.D. | |
| 6<br>Leveling | 1 | 141.0 | 145.0 | 147.5 | 148.5 | 146.4 |
| | 2 | 141.0 | 145.0 | 151.9 | 150.7 | 145.2 |
| | 3 | 137.8 | 143.0 | 147.6 | 148.6 | 138.3 |
| | 4 | 137.3 | 142.7 | 144.0 | 147.7 | 143.0 |
| | 5 | 135.2 | 141.4 | 150.8 | 149.9 | 148.2 |
| | 6 | 132.6 | 139.8 | 148.8 | 149.1 | 148.3 |
| | 7 | 136.8 | 142.4 | 147.5 | 148.5 | 142.3 |
| | 8 | 136.8 | 142.4 | 147.4 | 148.7 | --- |
| | 9 | 133.7 | 140.5 | 147.4 | 148.7 | 139.4 |
| | 10 | 142.6 | 145.9 | 144.9 | 147.2 | --- |
| | Avg. | 137.5 | 142.8 | 147.8 | 148.8 | 143.9 |
| | Std. Dev. | 3.27 | 2.00 | 2.36 | 0.99 | 3.79 |