FINAL REPORT

EVALUATION OF TROXLER MODEL 3411 NUCLEAR GAGE

by

David C. Wyant
Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

October 1978
VHTRC 79-R6

0618

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ABSTRACT

The performance of the Troxler Electronics Laboratory Model 3411 nuclear gage was evaluated through laboratory tests on the Department's density and moisture standards and field tests on various soils, base courses, and bituminuous concrete overlays throughout the state. From this work five recommendations were developed and submitted to the Department. The three most significant recommendations were (1) that with the Troxler 3400 series gages, the 6-inch direct transmission mode of testing be used with the roller pattern method of compliance testing for density on base courses; (2) that the Materials Division's moisture calibration standards be assigned moisture content values of 0, 7, and 17 lb./ft.^{3}; and (3) that the Department not purchase direct readout gages without further evaluation.

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INTRODUCTION

Since the early sixties the Department has purchased nuclear surface moisture-density gages for use in testing for compliance with specifications and at present has 150 of these devices in use. The continual purchasing of improved models of the gages as they become available on the market necessitates a concomitant program to evaluate them. The study reported here was initiated to examine the performance of one of the nuclear devices; namely, the Troxler Electronics Model 3411 gage.

TROXLER 3400 SERIES GAGES

The Troxler 3400 series nuclear gages are the latest series of gages marketed by Troxler Electronics Laboratories in Raleigh, North Carolina. They can be supplied with or without a direct readout feature. Without this feature the gage (Model 3401) requires calibration curves or charts as did the older series of gages. However, these curves or charts are not needed when the direct readout feature is supplied (Model 3411). This series will also provide the moisture content and density in either metric or English units. Several improved features cited by the manufacturer of the 3400 series gages are (1) their capability to simultaneously determine the density and moisture content values; (2) improved accuracy on rough surfaces; (3) a liquid crystal display that increases the readability in bright light conditions; (4) automatic correction of the density and moisture content values for the hydrogen (in the form of organic material) in the soil; and (5) a reduced sensitivity of the moisture determinations to the density of the test material.

From among the eleven 3400 series gages purchased in the summer of 1977, a Model 3411, which has the direct readout feature and memory storage of calibration curves or charts, was obtained for evaluation.

OBJECTIVES

The objectives of this study were to ascertain the accuracy of the Model 3411 Troxler Electronics nuclear gage in determining in absolute units (1) the density and moisture content of soils and base courses, and (2) the density of bituminous concrete.

PROCEDURE AND SCOPE

Laboratory Work

In the laboratory evaluation, the Model 3411 gage was tested on the Department's density and moisture standards used for calibrating nuclear gages. Ten tests were run on each standard. The density tests were conducted in four modes: backscatter and 4-inch, 6-inch, and 8-inch direct transmission.

Field Work

Soils and Base Courses

In evaluating the accuracy of the Model 3411 gage in determining the density and moisture content of soils and base courses, the sand cone method of density determination and the oven drying method for moisture content determination were used for comparisons. Three projects in each of the three major physiographic areas of the state were selected for testing on both soil and base courses. In some cases the same project was used for the soil and the base course tests.

At randomly selected locations on each project nuclear and sand cone tests were conducted, with the nuclear tests being run first. The entire sample of soil or base material extracted from the test hole for the sand cone test was tightly sealed in a jar and taken to the laboratory. There, it was weighed and oven dried at 105°C for dry weight and moisture content determinations.

Bituminous Concrete

For the evaluation of the gage on bituminous concrete, five projects throughout the state with completed base courses (B-3) were selected. Because of time limitations, only one surface course (S-5) was tested. Nuclear tests in the backscatter mode were conducted at ten locations on each project after it had been determined that the pavement layers met density specifications. At the completion of the nuclear tests, cores were extracted for density determinations in the laboratory by the specific gravity method.

RESULTS

Laboratory Work

Density

Table 1 lists the density results obtained in the laboratory evaluation.

TABLE 1

Laboratory Density Results, lb./ft.^{3}
(Average of 10 Tests)

Standard	Actual Density	Backscatter Mode	Direct Transmission Mode		
			4-Inch	6-Inch	8-Inch
Magnesium	110.26	110.63	109.86	109.53	109.02
Laminated Mg-AL	138.18	135.63	134.96	134.98	132.32
Limestone	140.55	148.41	144.94	143.46	143.08
Granite	164.05	163.50	162.88	162.46	161.76
Aluminum	168.35	162.82	162.48	162.32	162.18

From this table it can be seen that the backscatter mode of density testing determines the actual density of the standards better than the other modes, except on the limestone standard where the 8-inch mode is best. These results would seem to indicate one of two things: (1) either the backscatter mode determines the density better than do the other modes, which is contrary to the results obtained with the older nuclear gages, or (2) the average density is not uniform throughout the standards.

Although the individual results indicate that the backscatter mode is the best for most of the standards, it is prudent to compare modes over the entire range of densities expected in the field since there are errors due to composition, surface roughness, and nonuniformity in the standards. Table 2 lists the results from a linear least square computation for each of the four modes (the least squares method is given in the Appendix). As shown, the correlation coefficient increases with depth, while the standard error decreases. Table 2 indicates that the Model 3411 performs best in the 6-and 8-inch direct transmission modes on the known standards. Although the standard errors for these modes differ, the difference is insignificant.

TABLE 2

Least Squares Results From Density Standards

Mode	Correlation Coefficient	Standard Error, lb./ft.^{3}
Backscatter	0.956	5.35
Direct Transmission		
4-Inch	0.975	3.99
6-Inch	0.983	3.36
8-Inch	0.983	3.32

To check on the manufacturer's claim that the Model 3411 gage gave a lower error from surface roughness due to improved technology than the older models, the 3411 was tested on the limestone density standard over an 0.05-inch air gap and in the conventional manner. The differences in results are shown in Table 3. Also listed in Table 3 are the results supplied by the manufacturer.

TABLE 3

Surface Roughness Error, lb./ft.^{3}

Mode	Determined	Claimed
Backscatter	4.5	4.0
6-Inch Direct Transmission	0.3	0.9

As can be seen, there are some differences between the values given by the manufacturer and those from the tests. However, the differences are small and insignificant.

Moisture

The average results from ten tests on each of the Department's moisture standards are shown in Table 4.

TABLE 4

Laboratory Moisture Results, lb./ft.^{3}
(Average of 10 Tests)

Standard	Calculated	Measured
Magnesium	0.0	0.14
Low Moisture	9.0	7.11
High Moisture	20.1	16.97

Linear least squares computations on the values in Table 4 yielded a correlation coefficient of 0.999 and a standard error of 0.46 $lb./ft.^3$.

Table 4 shows that the moisture content obtained with the Model 3411 gage was lower (on the dry side) than the calculated value. The result for the low moisture standard was approximately 2 $lb./ft.^3$ lower and that for the high moisture standard approximately 4 $lb./ft.^3$ lower. Therefore, a shift in the moisture content values of the standards or a recalibration of the Model 3411 gage will probably be required. This shift or recalibration will be discussed later in the report.

Field Work

Density

Soils

Table 5 shows the wet density results for the soil projects evaluated. On the average for the nine soil projects, the sand cone method yielded results 4.0 $lb./ft.^3$ higher than did the backscatter mode. Compared to the results for the 6-inch direct transmission mode, the sand cone results were on the average 3.9 $lb./ft.^3$ lower.

If the sand cone density value is considered the standard, then the 6-inch direct transmission mode should yield results closer to the standard than the backscatter mode. From these results it is recommended that the 6-inch direct transmission mode be retained in testing for compliance with density specifications on subgrades with the Troxler 3400 series gages. Although only the Model 3411 gage was evaluated in this study, the Model 3401 gage (the other Troxler Model in the 3400 series) should have yielded the same results using the manufacturer's calibration curves. Therefore, this method of testing subgrades will be consistent with the methods utilized with all the other models of nuclear gages owned by the Department.

TABLE 5

Soils Results, lb./ft.^{3}

Location	Sand Cone			Backscatter		6-Inch Direct Transmission	
	No. of Tests	Wet Density	Std. Dev.	Wet Density	Std. Dev.	Wet Density	Std. Dev.
Piedmont							
Rte. 15	10	133.5	4.4	134.6	3.8	135.4	3.1
Rte. 29	10	112.3	6.0	117.5	5.0	121.6	3.7
Rte. 220	10	118.6	2.6	110.6	7.9	120.6	4.1
Valley							
Rte. 481	10	112.5	7.7	116.7	5.3	118.8	8.6
I-64-1	10	129.3	7.4	118.5	13.9	133.8	4.5
I-64-2	10	124.1	9.5	---	---	133.4	6.7
Coastal Plain							
Rte. 17	10	119.9	8.0	113.3	8.9	125.3	6.0
Rte. 32	10	126.0	3.4	122.2	3.8	126.3	6.1
I-264	10	127.3	6.0	115.7	2.6	123.5	3.3
Average							
9 Projects		122.6	6.1	118.6	6.4	126.5	5.1

Base Courses

Table 6 lists the wet density results for the base course projects evaluated. On the average for the nine projects, the backscatter mode yielded a wet density 9.5 lb./ft.^{3} lower than the sand cone results. The 6-inch direct transmission mode yielded a wet density on the average 1.7 lb./ft.^{3} lower than the sand cone value. In addition, the standard deviation for the 6-inch direct transmission results on each project was much lower than that for the backscatter results.

At present the Department is using the roller pattern method with the backscatter mode for density compliance testing on base courses. From the results in Table 6, it is recommended that on base courses the Department continue to use the roller pattern method and that the 6-inch direct transmission mode of density compliance testing be adopted in place of the backscatter mode with the Troxler 3400 series gages. (In performing the direct transmission test on base courses it is very important to hold the guide plate securely in place when driving and pulling the drill rod. If the plate is held securely in place, there should be no problem such as flaking off of the base course material or closing of the hole.)

TABLE 6

Base Course Results, lb./ft.^{3}

Location	Sand Cone			Backscatter		6-Inch Direct Transmission	
	No. of Tests	Wet Density	Std. Dev.	Wet Density	Std. Dev.	Wet Density	Std. Dev.
Piedmont							
Rte. 66	8	136.2	4.9	133.2	9.2	136.1	3.6
Rte. 60	10	147.0	3.9	131.2	7.0	141.7	4.4
Rte. 15	10	129.6	2.8	124.1	3.5	126.8	2.0
Valley							
Rte. 624	9	136.3	3.7	132.8	6.9	---	---
I-64-1	9	138.7	4.9	127.3	10.0	143.8	3.3
I-64-2	9	138.0	2.4	124.3	14.7	139.3	3.7
Coastal Plain							
Rte. 604	10	137.5	10.2	123.7	12.7	133.4	6.4
Rte. 665	10	150.2	7.9	142.1	3.2	144.4	1.7
I-64	10	142.9	6.3	131.9	7.8	137.8	4.6
Average							
9 projects		139.6	5.2	130.1	8.3	137.9	3.7

Bituminuous Concrete

Table 7 gives the backscatter density results obtained from six bituminuous concrete projects. The projects included five B-3 courses and one S-5 plant mix. Cores were obtained from each nuclear test location for density determination by an apparent specific gravity method using the equation

$$\gamma = \frac{(\text{Dry Weight})}{(\text{Dry Weight} - \text{Weight in Water})}$$

The results indicated that on all projects the nuclear gage determined the density to be lower on the average than the core density value. The differences between the results for the two methods varied from 0.8 (Rte. 37) to 9.7 (Rte. 66-2) lb./ft.^{3}. Because of these large variations one can conclude that the Model 3411 gage does not always measure the actual density (assuming the core value is the correct density) on bituminuous concrete mixes. Therefore, it is recommended that the Department use the backscatter mode with the roller pattern method in testing for compliance with the density specifications on bituminuous concrete with the Troxler 3400 series gages.

TABLE 7

Bituminuous Concrete Results, lb./ft.^{3}

Location	No. of Tests	Cores		Nuclear	
		Density	Std. Dev.	Backscatter Density	Std. Dev.
B-3					
Rte. 66-1	10	148.2	1.7	139.6	4.4
Rte. 311	10	148.3	2.2	145.7	2.3
Rte. 66-2	10	149.5	1.5	139.8	3.6
Rte. 37	10	147.8	1.6	147.0	6.2
Rte. 624	10	151.9	1.4	146.0	3.6
S-5					
I-77	8*	144.9	2.9	142.5	5.3
Average					
6 projects		148.4	1.9	143.4	4.2

* Two cores fell apart.

Moisture

Soils

Moisture content results on the nine soil projects are shown in Table 8. In all but one case the nuclear value was higher than the oven dried value. (The percent moisture content determined by the oven dried method was converted to pounds per cubic foot by multiplying by the dry density determined with the sand cone.) The trend is that the higher the moisture content, the more the two methods differ. Most of the difference at the higher moisture contents is likely due to the hydroscopic moisture or chemically bound moisture attached to clay particles and not evaporated off at 105°C in the oven.

At the lower moisture contents the difference is small enough that it would probably go unnoticed in the field.

TABLE 8

Moisture Content Results for Soils, lb./ft.^{3}

Location	No. of Tests	Oven		Nuclear	
		Moisture Content	Std. Dev.	Moisture Content	Std. Dev.
Piedmont					
Rte. 15	10	6.2	.8	7.0	.8
Rte. 29	10	17.3	1.5	20.6	3.2
Rte. 220	10	17.6	1.4	22.1	1.9
Valley					
Rte. 581	10	11.9	3.5	9.2	2.6
I-64-1	10	11.8	2.1	12.4	2.4
I-64-2	10	8.6	3.1	9.7	3.0
Coastal Plain					
Rte. 17	10	12.2	2.4	14.2	2.9
Rte. 32	10	12.8	2.6	13.9	2.5
I-264	10	8.6	1.3	8.7	1.2
Average					
9 projects		11.9	2.1	13.1	2.3

Base Courses

The same trend of the nuclear results being higher than the oven dried results was noticed in testing the base course (Table 9). On the average for the nine projects, the nuclear results were 1.2 lb./ft.^{3} higher than the oven dried results. The standard deviations for both modes are similar and low in value.

TABLE 9

Moisture Content Results for Base Courses, lb./ft.^{3}

Location	No. of Tests	Oven Moisture Content	Oven Std. Dev.	Nuclear Moisture Content	Nuclear Std. Dev.
Piedmont					
Rte. 66	8	4.2	1.4	5.3	1.5
Rte. 60	10	4.7	.9	7.0	1.4
Rte. 15	10	3.4	1.1	4.1	.7
Valley					
Rte. 624	9	2.2	.9	2.6	.8
I-64-1	9	2.3	.2	3.3	.4
I-64-2	9	3.1	.4	4.0	.3
Coastal Plain					
Rte. 604	10	5.7	1.9	7.0	2.2
Rte. 665	10	4.2	.5	4.7	.5
I-64	10	3.7	.9	4.6	1.0
Average 9 projects		3.7	.9	4.7	1.0

As discussed earlier in the laboratory moisture content evaluation phase, the Model 3411 gage did not reproduce the values of the Department's moisture standards (Table 4). Figure 1 is a plot of the Department's present moisture calibration curve (VDHT curve), the manufacturer's calibration curve provided with the gage (stored in the computer memory of the Model 3411 gage [Troxler curve]), and the linear curve of best fit computed for this study (1977 curve). As shown, the Department's present curve yields a higher moisture content than either of the other two for the same count ratio.

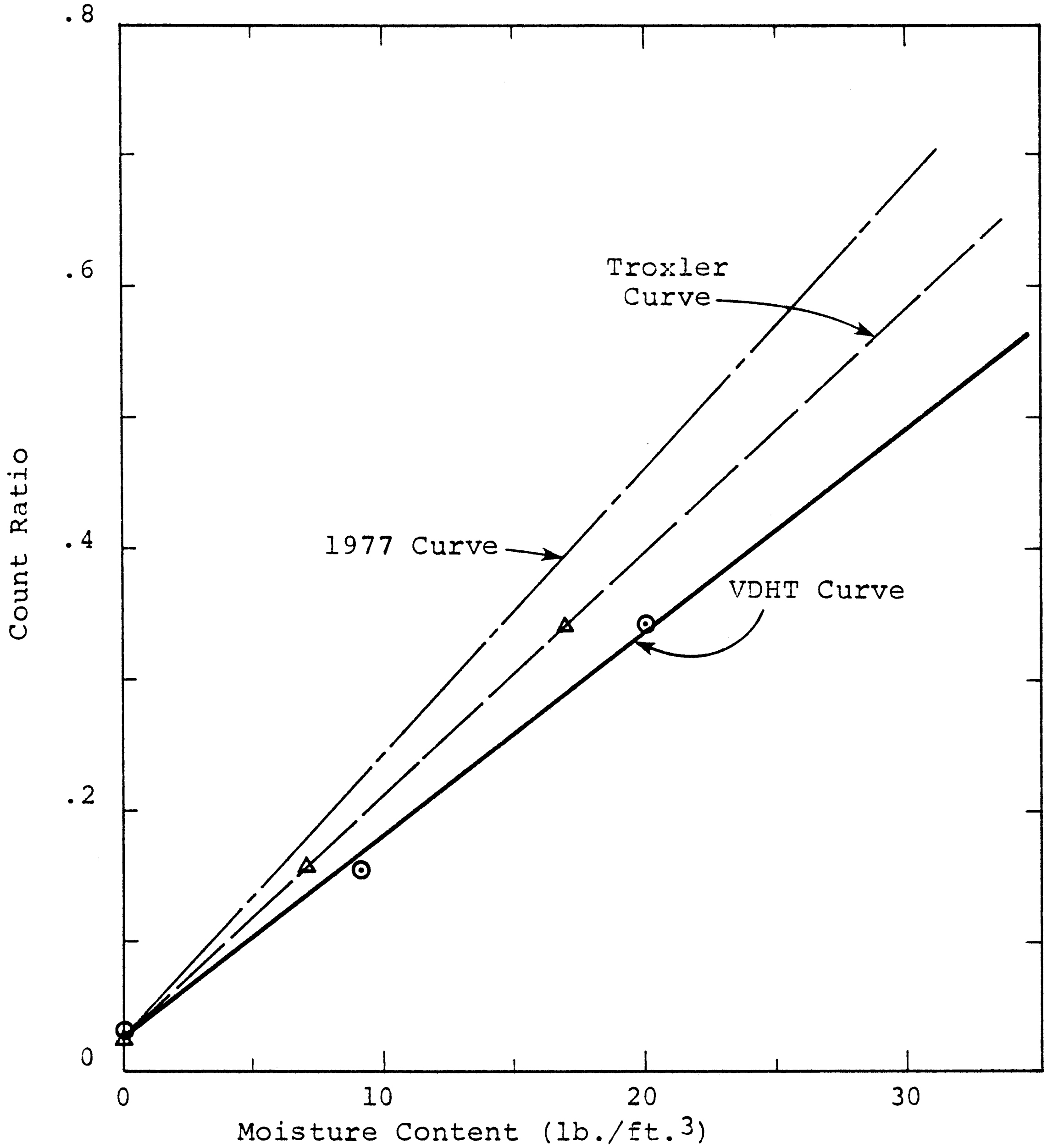

Figure 1. Moisture calibration curves.

In light of these findings and information obtained in conversations with personnel using the nuclear gages in the field it is believed that the moisture calibration curve supplied with the Department's gages should be shifted to the left or toward a lower moisture content for the same count ratio. As noted in conversations with the field personnel and shown in most cases in Tables 8 and 9, the materials with high moisture contents create most of the problems. (At the high moisture contents the curves separate further.) Since every soil type and situation was not and cannot be checked, it is felt that the moisture calibration curve should be shifted so it reproduces the Troxler calibration curve. This shift will closely follow the shift applied to only the Troxler Model 1401 gages in 1976. If problems persist during the 1978 construction season, then the calibration curve may have to be shifted again to reproduce the results found in this study.

At present the Department is using three primary moisture standards of 0, 9, and 20.1 lb./$ft.^3$ moisture contents as calibration blocks. With the above described shift the two higher moisture content blocks will be assigned moisture content values of 7 and 17 lb./$ft.^3$, respectively, thus making the blocks secondary standards. Therefore, it is recommended that the moisture calibration standards in the Materials Division be reassigned moisture content values of 0, 7, and 17 lb./$ft.^3$.

General

There are two models in the Troxler 3400 series of nuclear gages. One is the 3401 gage, which is improved technologically but is similar to the Troxler Model 2401 gage. The other is the 3411 gage, which is the direct readout gage evaluated in this study. The difference between these two models is that the 3411 stores the calibration curves in its computer and provides a direct readout of the moisture content, dry density, and wet density, whereas the 3401 provides only moisture and density counts. This direct readout feature costs approximately $500. Another consideration when purchasing a nuclear gage is the calibration process. The direct readout model 3411 gage is calibrated at the factory by the manufacturer. If the calibration curves need to be shifted, the input data for a shift will have to be sent with the processor (calibration curves storage unit) to the factory for recalibration. This process would take approximately two weeks.

With the Model 3401 gage the calibration curve or curves could be produced by the Department within a short period of time after calibration. Therefore, with the Department owning its moisture and density calibration standards it is recommended that the Department not purchase direct readout gages without further evaluation.

CONCLUSIONS

The Troxler Model 3411 gage has several new features which reduce the time required in testing. Two of these features are (1) the simultaneous determination of density and moisture content, and (2) the direct readout of the wet density, the dry density, the percent moisture, and the pounds per cubic foot moisture. However, because the manufacturer is the only one able to change the calibration curves in the Model 3411 gage and the readout capability costs approximately $500, the Troxler Model 3401 gage would be the better model to purchase. The Materials Division can calibrate the Model 3401 gage the same as it does the older model gages.

Based on the findings of this study, the moisture calibration standards should be assigned lower moisture values of 7 and 17 lb./ft.^{3}. By changing the moisture content of the standards, the moisture calibration curve provided with the Department's gages will be more in line with that provided by the manufacturer. In other words, for the same count ratio the new calibration curve will yield a lower moisture content.

RECOMMENDATIONS

The following recommendations are made on the basis of the findings of this study.

1. The 6-inch direct transmission mode of density testing should be retained in compliance testing on subgrades with the Troxler 3400 series gages.

2. The Department should continue to use the roller pattern method and should adopt the 6-inch direct transmission mode of density testing for compliance with specifications in place of the backscatter mode with the Troxler 3400 series gages.

3. The Department should continue to use the backscatter method of testing for compliance with density specifications on bituminuous concrete with the Troxler 3400 series gages.

4. The moisture calibration standards in the Material's Division should be reassigned moisture content values of 0, 7, and 17 $lb./ft.^3$.

5. The Department should not purchase direct readout gages without further evaluation.

ACKNOWLEDGMENTS

The author thanks M. O. Harris, technician, and Robert Hampton, student helper, at the Research Council for their help in collecting data. In addition, thanks go to M. C. Anday and C. S. Hughes of the Council for their guidance and general comments during the study. Special thanks are extended to the field forces and the district personnel conducting the Department's nuclear testing program for their cooperation and assistance on each project. The author thanks Barbara Turner of the Research Council for handling clerical details involved in the study.

APPENDIX

Method of Least Squares

The curve of best fit using the method of least squares is based on the assumption that the location of the curve is such as to make the sum of the squares of the differences of the known and unknown values a minimum. Using the linear curve of best fit, y = mx + b, the least squares method obtains

$$\Sigma(y-mx-b)^2 = \text{minimum},$$

where

m is the slope of the line, and

b is the intercept on the y-axis.