NUCLEAR FIELD DENSITY PROBLEMS

by

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Virginia Highway & Transportation Research Council
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SUMMARY

The densities of subgrade soils at various locations throughout the state were determined using the different model nuclear gages owned by the Department. In addition, some laboratory testing and sand core testing were carried out. It was concluded that the direct transmission-standard mode of nuclear density determination could replace the presently used air gap-direct transmission mode. A recommendation covering this improvement is made to the Department.

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RESEARCH NEED

In late summer of 1973, the Research Council was requested by the Materials Division to help evaluate a suspicion on the part of personnel in one of the construction districts that the nuclear gages, which were adopted for soil moisture and density testing in 1965, were requiring less density from the contractor than did the old methods of checking compaction (sand cone and oil methods).

Initially it was intended that the evaluation would be restricted to the problem district. However, after the evaluation of three projects in that district, it was conjectured that the situation suspected to exist there might also exist in other districts. Because the results from the initial three projects neither confirmed nor dispelled the suspicion held, and the fact that although the nuclear gages had been the object of numerous trouble-shooting level investigations since they were adopted but no overall reassessment had been made, the study reported here was initiated.

INVESTIGATIVE APPROACH

In the evaluation of the initial three projects in the problem district, the Materials Division tested one of its nuclear gages along with the Research Council's Troxler Model 2401 gage, while the Research Council ran comparative tests with their sand cone equipment.

For each project a section of the subgrade that had been compacted and then passed by the inspector's nuclear gage was chosen as the test area. Five sites were randomly selected throughout the section for testing with the two nuclear gages and the sand cone (S.C.). Each site was tested with the nuclear gages in all four density modes (backscatter-standard (B.S./Std.)), air gap-backscatter (A.G./B.S.), direct transmission-standard (D.T./Std.), and air gap-direct transmission (A.G./D.T.).

After completion of testing on the three selected projects, the data were analyzed to determine if any trends existed between the nuclear data and the sand cone data. It was ascertained that no trends were very evident and further evaluation was necessary. In other words, the data did not correlate very well.

Therefore, the author decided that at least three projects in each of the three major physiographic areas needed to be evaluated to determine if any density problems existed. Nine additional projects were chosen to be evaluated by the Research Council's nuclear gage and sand cone. The total number of projects evaluated thus was 12 (see Figure 1).

It was anticipated, because of the inherent inaccuracies and variabilities in both methods, that the sand cone and nuclear density values would not compare exactly and means for establishing a standard density was sought. Therefore, after completion of the field testing approximately 200 pounds (90.7 kg) of representative soil from each test section were brought back to the laboratory. This material was air dried, seived over a No. 4 screen, and classified by general soil tests. Each soil was then compacted by static and dynamic loading in a 17-inch (43.2 cm) diameter, 7-inch (17.8 cm) high mold to a density and moisture content comparable to those in the field. The density and moisture content of the compacted material in the mold were first determined after compaction by gravimetric and volumetric methods. This density represented the best measure of a standard density that could be obtained. Nuclear moisture contents and densities in the four modes were determined next. These tests were followed with the sand cone evaluation of the density of the compacted soil. The moisture content used with the sand cone density was determined by placing a sample in the oven at 110° C. This moisture content also represents the moisture content of the mold itself.

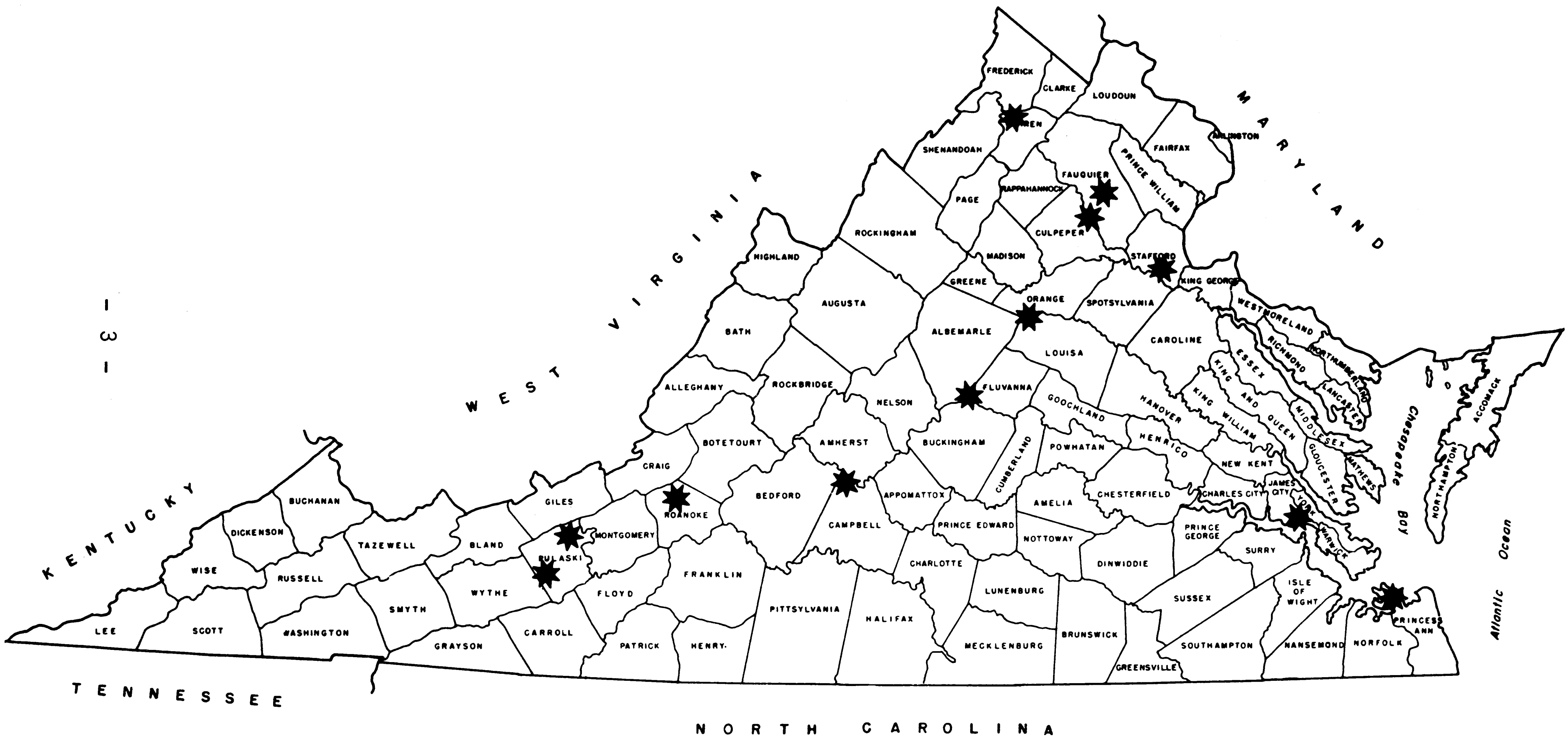

Figure 1. Project locations.

RESULTS

Table 1 shows the density data collected on the first three projects evaluated in this study with the Research Council's Model 2401 gage. Two of the projects were in the Piedmont physiographic area. The densities of the soils were determined by the four modes with the nuclear gage. All the data are an average of the results from the five sets of tests in a test section. Although the sand cone densities [average 113.1 pcf (1.81 g/cc)] and the B.S./Std. densities [average 114.0 pcf (1.83 g/cc)] correlated fairly well, the author felt that further research was necessary. The main reason for further work was that the field forces of the Department were using the A.G./D.T. mode for determining densities of subgrades, and this mode did not correlate well with either the S.C. or B.S./Std. Also, as previously mentioned, a standard density measure was thought to be desirable to help indicate which density was most correct.

Table 1

Initial Three Projects in Problem District

		Density (pcf)/(g/cc)			
		Piedmont		Coastal Plain	Average for 3 Projects
Method of Test		#1	#2	#3	
Sand Cone		106.4(1.70)	121.4(1.94)	111.6(1.79)	113.1(1.81)
Nuclear	B.S./Std.	107.6(1.72)	121.1(1.94)	113.3(1.82)	114.0(1.83)
Nuclear	D.T./Std.	115.9(1.86)	128.2(2.05)	125.5(2.01)	123.2(1.97)
Nuclear	A.G./B.S.	112.8(1.81)	119.5(1.91)	119.6(1.92)	117.3(1.88)
Nuclear	A.G./D.T.	118.5(1.90)	127.2(2.04)	128.5(2.06)	124.7(2.00)

B.S. — Backscatter Density Mode

A.G. — Air Gap Density Mode

D.T. — 6 inch (15.24 cm) Direct Transmission Density Mode

Std. — Standard Density Count

After the selection of the nine additional projects, field and laboratory research was carried out over several months. Tables 2 and 3 show the final data for all the work. In Table 3 an additional density value is shown. The density labelled "mold", considered the standard density, was obtained by gravimetric and volumetric means from the 17-inch (43.2 cm) diameter, 7-inch (17.8 cm) high mold.

Table 2

Field Density Data

Density (pcf)/(g/cc)

Method of Test	Piedmont					Coastal Plain			Valley and Ridge			
Sand Cone	113.0 (1.81)	116.1 (1.86)	115.1 (1.84)	106.4 (1.70)	121.4 (1.95)	129.8 (2.08)	131.0 (2.10)	111.6 (1.77)	121.2 (1.94)	123.0 (1.97)	117.6 (1.88)	111.4 (1.78)
B.S./Std.	108.5 (1.74)	104.5 (1.67)	109.4 (1.75)	107.6 (1.72)	121.1 (1.94)	126.1 (2.02)	123.8 (1.98)	113.3 (1.82)	113.3 (1.82)	120.3 (1.93)	115.3 (1.85)	112.9 (1.81)
D.T./Std.	120.8 (1.94)	118.2 (1.89)	116.3 (1.86)	115.9 (1.86)	128.2 (2.05)	130.0 (2.08)	125.6 (2.01)	125.5 (2.01)	128.5 (2.06)	124.2 (1.99)	122.2 (1.96)	118.3 (1.90)
A.G./B.S.	114.9 (1.84)	111.1 (1.78)	113.9 (1.82)	112.8 (1.81)	119.5 (1.91)	130.5 (2.09)	129.9 (2.08)	119.6 (1.92)	119.0 (1.91)	124.2 (1.99)	120.4 (1.93)	117.9 (1.89)
A.G./D.T.	123.9 (1.98)	121.3 (1.94)	118.5 (1.90)	118.5 (1.90)	127.2 (2.04)	132.3 (2.12)	128.9 (2.07)	128.5 (2.06)	131.1 (2.10)	126.2 (2.02)	124.8 (2.00)	121.0 (1.94)

Table 3

Laboratory Density Data

Density (pcf)/(g/cc)

Method of Test	Piedmont			Coastal Plain		Valley and Ridge			
Mold	110.0 (1.78)	94.4 (1.51)	108.2 (1.73)	123.9 (1.98)	131.4 (2.11)	114.3 (1.83)	112.6 (1.80)	102.5 (1.64)	100.3 (1.61)
Sand Cone	113.3 (1.82)	92.6 (1.48)	106.4 (1.70)	120.1 (1.92)	133.1 (2.13)	112.7 (1.81)	115.2 (1.85)	97.0 (1.55)	97.3 (1.56)
B.S./Std.	111.4 (1.78)	92.8 (1.49)	104.8 (1.68)	118.5 (1.90)	123.0 (1.97)	111.5 (1.79)	109.3 (1.75)	99.0 (1.59)	99.5 (1.59)
D.T./Std.	111.8 (1.79)	95.2 (1.53)	109.0 (1.75)	123.5 (1.98)	129.5 (2.07)	116.5 (1.87)	116.0 (1.86)	102.0 (1.63)	105.8 (1.70)
A.G./B.S.	114.6 (1.84)	95.6 (1.53)	107.3 (1.72)	120.8 (1.94)	126.1 (2.02)	114.1 (1.83)	113.5 (1.82)	103.5 (1.66)	102.7 (1.65)
A.G./D.T.	113.6 (1.82)	96.7 (1.55)	110.3 (1.77)	124.8 (2.00)	131.0 (2.10)	118.0 (1.89)	118.1 (1.87)	104.3 (1.67)	104.5 (1.67)

Regression analyses were run between each two methods for all the data. The regression analyses on all the data yielded the correlation coefficients in Tables 4 and 5. In addition, the average density for all the projects for all the modes tested are shown.

Table 4

Percent Correlation Coefficients and Average Density From Field Projects (Data in Table 2)

Method of Test	B.S./Std.	D.T./Std.	A.G./B.S.	A.G./D.T.	Average Density (pcf)/(g/cc)
Sand Cone	83.3	73.2	84.5	73.3	118.1 (1.89)
B.S./Std.		78.1	94.8	73.7	114.7 (1.84)
D.T./Std.			74.4	97.3	122.8 (1.97)
A.G./B.S.				77.4	119.5 (1.91)
A.G./D.T.					125.2 (2.01)

Table 5

Percent Correlation Coefficients and Average Density From Laboratory Work (Data in Table 3)

Method of Test	Sand Cone	B.S./Std.	D.T./Std.	A.G./B.S.	A.G./D.T.	Average Density (pcf)/(g/cc)
Mold	97.9	98.5	98.3	98.4	99.0	111.0 (1.78)
Sand Cone		96.2	98.1	97.2	98.2	109.7 (1.76)
B.S./Std.			98.0	99.6	97.6	107.8 (1.73)
D.T./Std.				98.5	99.9	112.1 (1.80)
A.G./B.S.					98.5	110.9 (1.78)
A.G./D.T.						113.5 (1.82)

DISCUSSION OF RESULTS

In this discussion of the laboratory and field results, attention is focused on Tables 4 and 5 which are concerned with correlation coefficients and average densities. In Table 5 a standard, the mold value, is used as the value the other methods of measurement should approximate. It can be seen from Table 5 that the correlation of the methods of density measurement with the mold varies from 97.0% to 99.0%, which is considered to be almost identical. From the average density results, the mold (111.0 pcf - 1.78 g/cc) is closest (0.1 pcf - 0 g/cc) to the A.G./B.S. mode of density testing (110.9 pcf - 1.78 g/cc). The B.S./Stds. mode of testing yields the largest average density difference of 3.2 pcf (0.05 g/cc) below the standard.

At present, the Department's field personnel are using the A.G./D.T. mode of density testing because at one time with the older model gages, Troxler Model 227, it provided the best compensation for depth of test and composition effect. For this reason it was felt that one of the two modes of direct transmission density testing should be continued in use. Since the preceding results indicate that the average density differences from the mold density for the D.T./Std. and A.G./D.T. are 1.1 and 2.5 pcf (0.02 and 0.04 g/cc), respectively, the author recommended that the Materials Division start using the D.T./Std. mode of density testing in place of the A.G./D.T. mode for the Troxler Model 2401 gages. This change would eliminate the need for an air gap measurement for all Troxler Model 2401 gages, and thus save time and money in the specification compliance testing of subgrades.

In Table 4, which shows the field densities, the main concern is how well the four modes of nuclear density correlate with the old method of density compliance testing, the sand cone method. Most of the field correlation coefficients are lower than 85% and the laboratory coefficients. The sand cone average density correlates best with the A.G./B.S. and the B.S./Std. On the average the A.G./B.S. mode of density testing determines the density of a soil to be 1.4 pcf (0.02 g/cc) higher than the sand cone density, while the B.S./Std. mode yields a density of 3.4 pcf (0.05 g/cc) lower than the sand cone value.

The D.T./Std. and A.G./D.T. modes of testing vary further from the sand cone density [4.7 and 7.1 pcf (0.08 and 0.11 g/cc), respectively than the backscatter modes. As shown in the field, the D.T./Std. determines the density of the subgrade closer to the sand cone value than does the A.G./D.T. Under more ideal conditions in the laboratory these average differences in densities were reduced but followed the same trend (Table 6).

Table 6

Average Differences Between Nuclear and Sand Cone Densities, pcf (g/cc)

Nuclear Mode of Testing	Laboratory	Field
B.S./Std.	-1.9 (0.03)	-3.4 (0.05)
D.T./Std.	+2.4 (0.04)	+4.7 (0.08)
A.G./B.S.	+1.2 (0.02)	+1.4 (0.02)
A.G./D.T.	+3.8 (0.06)	+7.1 (0.11)

EXTENDED STUDY

The previously cited recommendation was presented to the Soils and Geology Research Advisory Committee in Fredericksburg, Virginia, on October 31, 1974, with the following condition. Although air gap measurements for Troxler Model 2401 gages can be eliminated, it was felt this elimination would create an inconsistency in testing with other gages. Therefore, it was decided at the above meeting that the Materials Division would collect data to determine if it was feasible to eliminate the air gap measurements for the Department's other gages, the Troxler Model 1401 and the Campbell Pacific.

Data were obtained by the Materials Division from six districts on the Troxler Model 1401 and Campbell Pacific gages. Tables 7 through 9 summarize the data received from the field. In Table 7 for the 6 inch (15.24 cm) depth values with the Troxler Model 1401 gages from four districts the average density using the A.G./D.T. mode of measurement is 122.5 pcf (1.96 g/cc), while the D.T./Std. mode value is 119.9 pcf (1.92 g/cc). The difference between the two modes of testing is 2.6 pcf (0.04 g/cc), which is slightly larger than the results obtained from the Research Council's Troxler Model 2401. It was determined for the Model 2401 on the data reported in the RESULTS section, that the average difference in the A.G./D.T. and D.T./Std. modes for 6-inch (15.24 cm) depth readings was 2.0 pcf (0.03 g/cc). As with the Model 1401, the A.G./D.T. densities averaged higher than the D.T./Std. densities.

Table 7

Troxler 1401 (6-inch)/(15.24 cm) Depth

(1) District	(2) A.G./D.T. (pcf)	(3) D.T./Std. (pcf)	(2) - (3) = Difference (pcf)
Culpeper	121.4	119.2	2.2
	119.7	118.2	1.5
	120.0	118.3	1.7
	120.7	118.7	2.0
	119.8	117.3	2.5
	120.5	118.9	1.6
Salem	124.3	123.4	0.9
	130.5	129.3	1.2
	126.5	126.0	0.5
	132.4	130.6	1.8
	119.8	118.1	1.7
	122.6	121.6	1.0
	123.5	122.6	0.9
	123.1	122.5	0.6
	126.8	125.4	1.4
	119.3	116.9	2.4
	119.5	117.3	2.2
	117.6	114.5	3.1
	124.5	126.4	-1.9
	118.5	116.0	2.5
	126.0	121.5	4.5
	121.0	116.0	5.0
	123.5	118.8	4.7
	121.4	115.8	5.6
	114.5	107.8	6.7
	124.3	120.8	3.5
	125.4	116.1	9.3

Table 7 (continued)

(1) District	(2) A.G./D.T. (pcf)	(3) D.T./Std. (pcf)	(2) - (3) = Difference (pcf)
Staunton	107.0	104.7	-2.3
	116.3	114.2	2.1
	118.9	115.8	3.1
	119.8	115.9	3.9
	122.8	119.3	3.5
	113.0	109.2	3.8
Suffolk	127.9	123.2	4.7
	128.9	128.3	0.6
	128.8	128.3	0.5
	131.2	128.8	2.4
	131.3	128.8	2.5
Average	122.5 pcf (1.96 g/cc)	119.9 pcf (1.92 g/cc)	2.6 pcf (0.04 g/cc)

Table 8

Campbell - Pacific (6-inch)/(15.24 cm) Depth

(1) District	(2) A.G./D.T. (pcf)	(3) D.T./Std. (pcf)	(2) - (3) = Difference (pcf)
Suffolk	123.6	120.8	2.8
	127.3	118.2	9.1
	124.3	121.0	3.3
	124.7	121.8	2.9
	127.2	122.8	4.4
	122.7	116.6	6.1
Fredericksburg	133.7	132.5	1.2
	133.9	127.8	6.1
	135.6	130.0	5.6
	136.4	130.2	6.2
	132.9	130.7	2.2
	126.9	123.0	3.9
	126.7	122.8	3.9
	127.3	122.8	4.5
	126.9	123.3	3.6
	127.7	122.8	4.9
Lynchburg	115.5	114.3	1.2
	113.3	115.0	-1.7
	116.0	115.5	0.5
	119.4	117.3	2.1
	113.0	112.3	0.7
	114.2	113.2	1.0
Average	125.0 pcf (2.00 g/cc)	121.6 pcf (1.95 g/cc)	3.4 pcf (0.05 g/cc)

Table 9

Campbell - Pacific (8-inch)/(20.32 cm) Depth

(1) District		(2) A.G./D.T. (pcf)	(3) D.T./Std. (pcf)	(2) - (3) = Difference (pcf)
Lynchburg		122.2	120.3	1.9
		126.1	123.4	2.7
		125.6	123.2	2.4
		116.6	114.0	2.6
		122.2	119.2	3.0
	Average	122.5 pcf (1.96 g/cc)	120.0 pcf (1.92 g/cc)	2.5 pcf (0.04 g/cc)

Table 8 shows the data and results obtained from three districts using Campbell-Pacific gages at a 6-inch (15.24 cm) depth. The A.G./D.T. and D.T./Std. modes averaged 125.0 and 121.6 pcf (2.00 and 1.95 g/cc), respectively. The difference between the averages is 3.4 pcf (0.05 g/cc). From the five data values supplied by the Lynchburg District for the 8-inch (20.32 cm) depth, the average A.G./D.T. and D.T./Std. values were determined to be 122.5 and 120.0 pcf (1.96 and 1.92 g/cc), respectively. The difference in the two averages is 2.5 pcf (0.04 g/cc).

In summary, for the three different gages at the 6-inch (15.24 cm) depth the average differences between the A.G./D.T. and D.T./Std. range from 2.0 to 3.4 pcf (0.03 to 0.05 g/cc). For the five 8-inch (20.32 cm) depth data sets from the Lynchburg District the average difference was 2.5 pcf (0.04 g/cc).

RECOMMENDATION

From the results of this study and the additional field data provided by the Materials Division the following recommendation is made: When nuclear gages are used in subgrade compliance testing, the direct transmission-standard mode of density testing replace the presently used air gap-direct transmission mode. Although the change would require slightly more compactive effort from the contractor than the present procedure requires, the recommended procedure would produce densities that more nearly agree with the true values.

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