INTERIM REPORT NO. 1

REFINEMENT OF MOISTURE CALIBRATION CURVES FOR NUCLEAR GAGE

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Virginia Highway Research Council
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INTRODUCTION

As stated in the working plan[1] for this study, the first two of the four objectives were to:

1. Generalize the conclusion that soils can be divided into two or more distinct groups on the basis of optimum moisture content, percent passing No. 200 screen, and percent sand.

2. Determine if the above conclusion is applicable to a more modern gage than the one used in the study, "Nuclear Measurement of Soil Properties" by M. C. Anday and C. S. Hughes[2].

These two objectives have been achieved and they are covered in this report. Research on the third objective, the determination of primary moisture standards, is in the initial phase and will not be reported in detail. If primary standards cannot be developed, then the fourth objective, which is the development of secondary moisture standards, will be pursued.

MATERIALS

In this study thirty-six soils were tested with the Troxler Model 227 gage, while twenty-nine soils were tested with the more modern Troxler Model 2401 gage. The soils were sampled from different geological formations to give a wide spread in chemical constituents and physical properties. The range of optimum moisture contents was from 5% to 40%. The physical characteristics of each soil are shown in Table I.

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TABLE I

PHYSICAL CHARACTERISTICS OF SOILS

Soil Identification No.	Maximum Density, pcf	Optimum Moisture, %	Liquid Limit, %	Plasticity Index, %	HRB Classification
1	89.8	30.5	55	22	A-7-5(15)
2	108.2	14.1	—	NP	A-3
3	116.8	12.2	47	19	A-2-7(2)
4	115.5	14.0	29	NP	A-4
5	108.3	17.8	40	17	A-6(6)
6	92.0	28.0	47	20	A-7-5(12)
9	102.0	21.2	34	8	A-4(8)
12	104.5	15.0	—	NP	A-3
13	89.0	31.8	53	17	A-7-5(13)
14	133.7	7.7	—	NP	A-2-4
15	78.9	39.2	74	NP	A-5(9)
17	138.5	10.0	19	NP	A-3
18	109.7	6.9	—	NP	A-3
19	106.5	8.7	—	NP	A-3
20	90.4	30.6	48	11	A-7-5(3)
21	106.1	16.5	37	6	A-4(1)
22	120.0	12.5	18	NP	A-2-4
23	119.1	12.3	19	2	A-2-4
24	118.7	13.4	—	NP	A-2-4
25	109.1	18.5	34	9	A-4(8)
26	94.4	27.5	48	12	A-7-5(8)
27	98.4	24.9	41	10	A-5(3)
29	102.1	21.2	36	9	A-4(5)
30	111.8	15.9	25	8	A-4
31	121.0	12.1	—	NP	A-3
32	112.8	16.1	23	5	A-2(4)
33	103.2	20.6	30	8	A-4
34	123.4	11.6	15	3	A-4
35	101.1	14.4	—	NP	A-3
36	104.2	11.8	—	NP	A-3
37	117.8	13.4	27	8	A-4
68-1	109.0	16.0	29	NP	A-4
68-5	88.1	32.5	36	NP	A-5
68-6	105.1	19.1	33	NP	A-4(1)
68-16	95.6	24.0	50	NP	A-5(1)
70-2	103.0	19.1	37	NP	A-4(1)

TESTING AND PROCEDURE

Each soil was molded at or near optimum moisture content and maximum density. Several soils were remolded for various reasons, which accounts for more data points than the number of soils sampled.

The soils were compacted in a 17" diameter 7" high mold by static and dynamic compactive efforts to obtain a uniform density. Following the moisture and density nuclear measurements with both model gages, the density and the moisture content of the molded samples were determined by volumetric and gravimetric methods.

RESULTS

Figure 1 shows the plot of all the data points for the Model 227 gage. The data points were obtained in both this study and the earlier study by M. C. Anday and C. S. Hughes.[2] The single calibration curve of best fit is also shown on the figure. The standard error of this curve is 2.7 pcf, which indicates a reasonably wide range in moisture contents for different soils at the same count ratio. This standard error is larger than the authors think practical for most specifications and will require field calibration for some soils in order to use the gage effectively. However, as stated in the working plan[1], two calibration curves could be used to reduce the standard error. In Figure 2 the data points are divided into two groups and plotted with the curve of best fit for each group. The two groups are divided at the 21% optimum moisture content level. The procedure for separation will be explained later. With the use of two calibration curves, the standard error is reduced considerably. For the lower moisture soils the standard error of the curve is 1.4 pcf, while for the curve for the other group it is 1.7 pcf.

Figure 3 is a plot of the data for the Model 2401 gage. There are fewer data points for this gage than the Model 227 gage, since it was used only in this study. As shown on the figure, the standard error for the single calibration curve is 1.7 pcf. This standard error is equivalent to the largest standard error of the two calibration curves of the Model 227 gage. The possible reasons for a single calibration curve with only a standard error of 1.7 pcf will be explained later.

Standard Error = 2.7 pcf
Correlation Coefficient = 0.904
Linear Regression Line $y = 0.015x + 0.38$

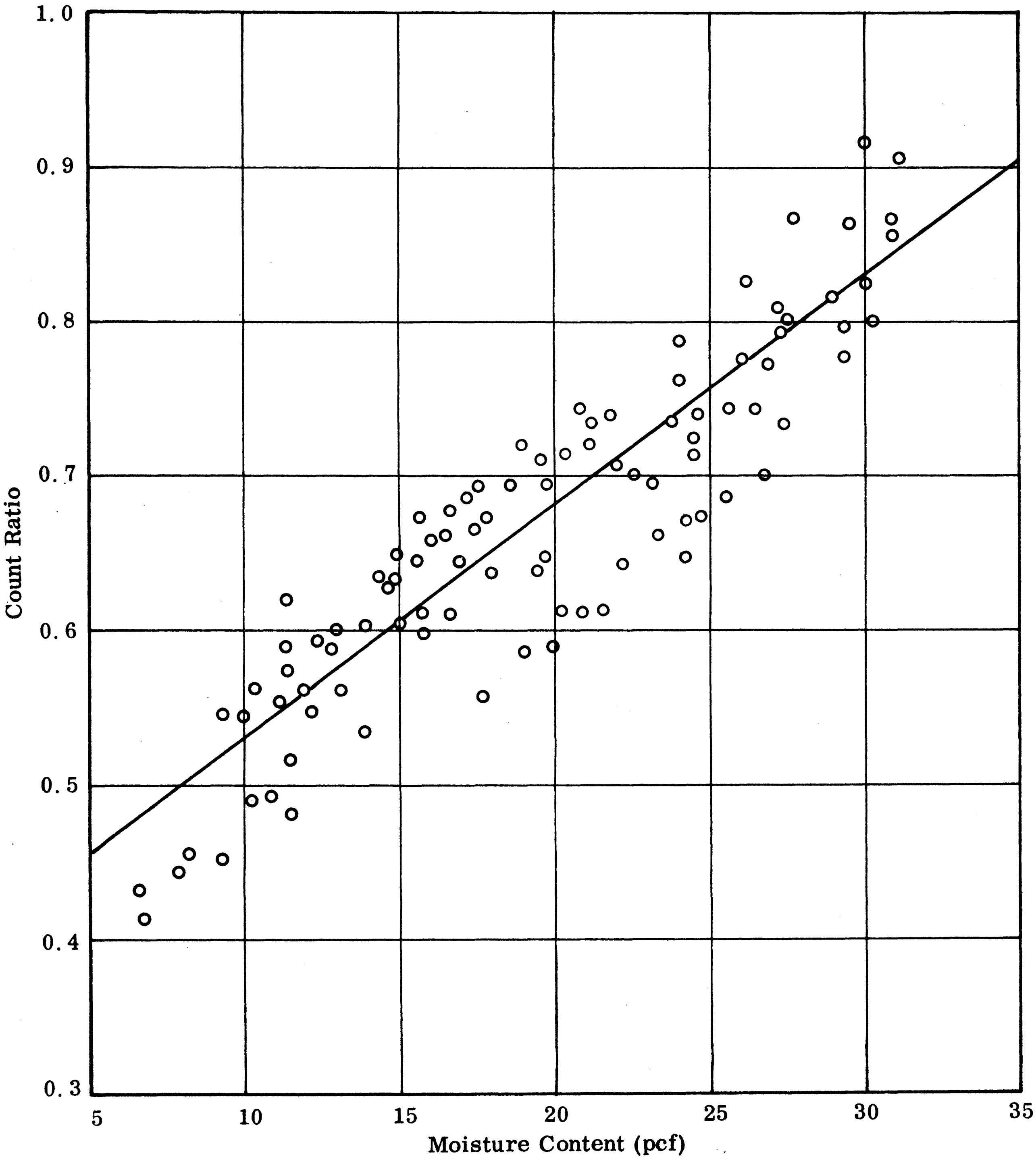

Figure 1. Single calibration curve for Model 227 gage.

For x Points

Standard Error	= 1.4 pcf
Correlation Coefficient	= 0.933
Linear Regression Line	y = 0.020x + 0.32

For o Points

Standard Error	= 1.7 pcf
Correlation Coefficient	= 0.878
Linear Regression Line	y = 0.022x + 0.19

Divided at 21% OMC Level

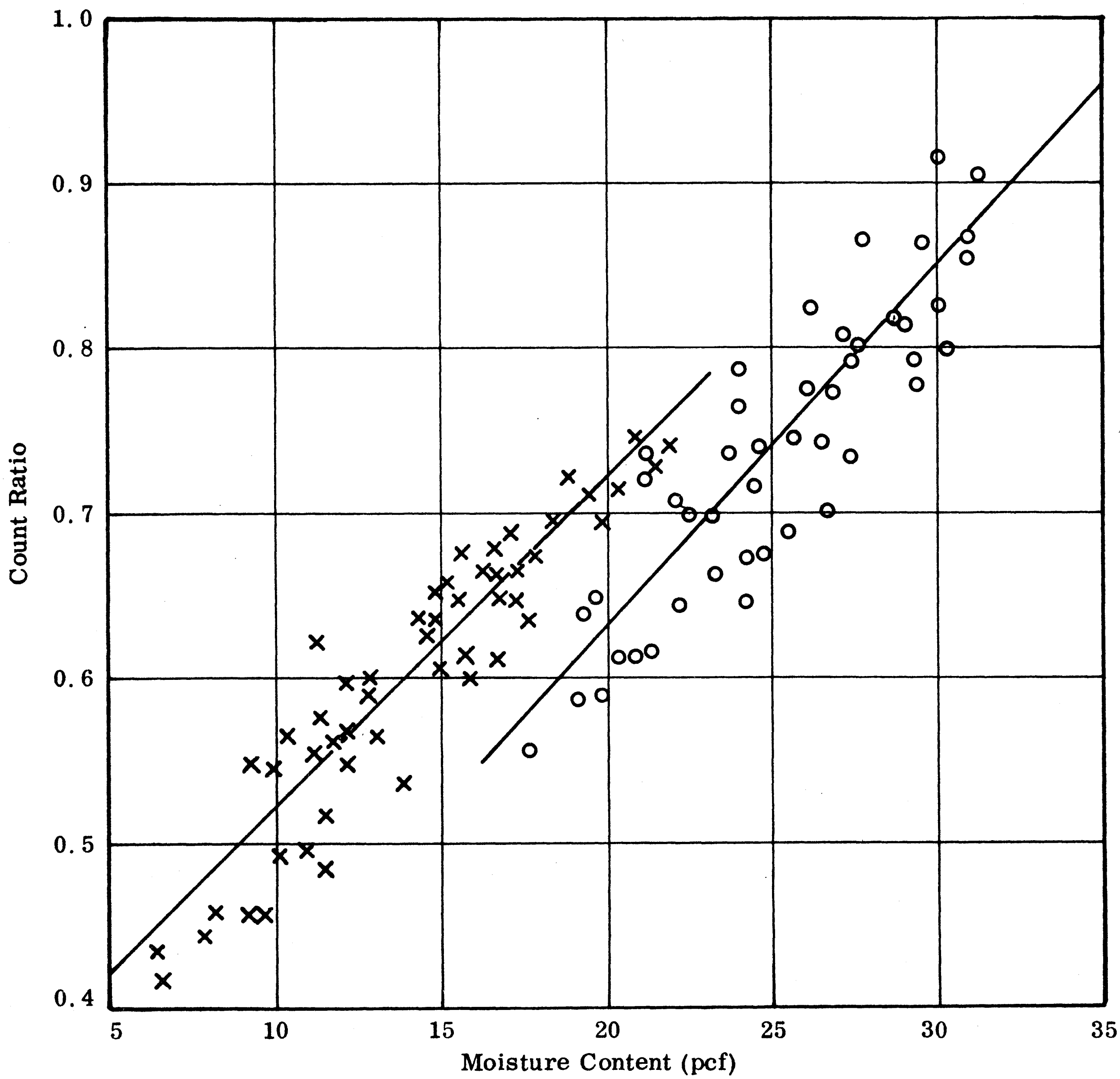

Figure 2. Two calibration curves for Model 227 gage.

Standard Error = 1.7 pcf
Correlation Coefficient = 0.967
Linear Regression Line $y = 0.036x + 0.20$

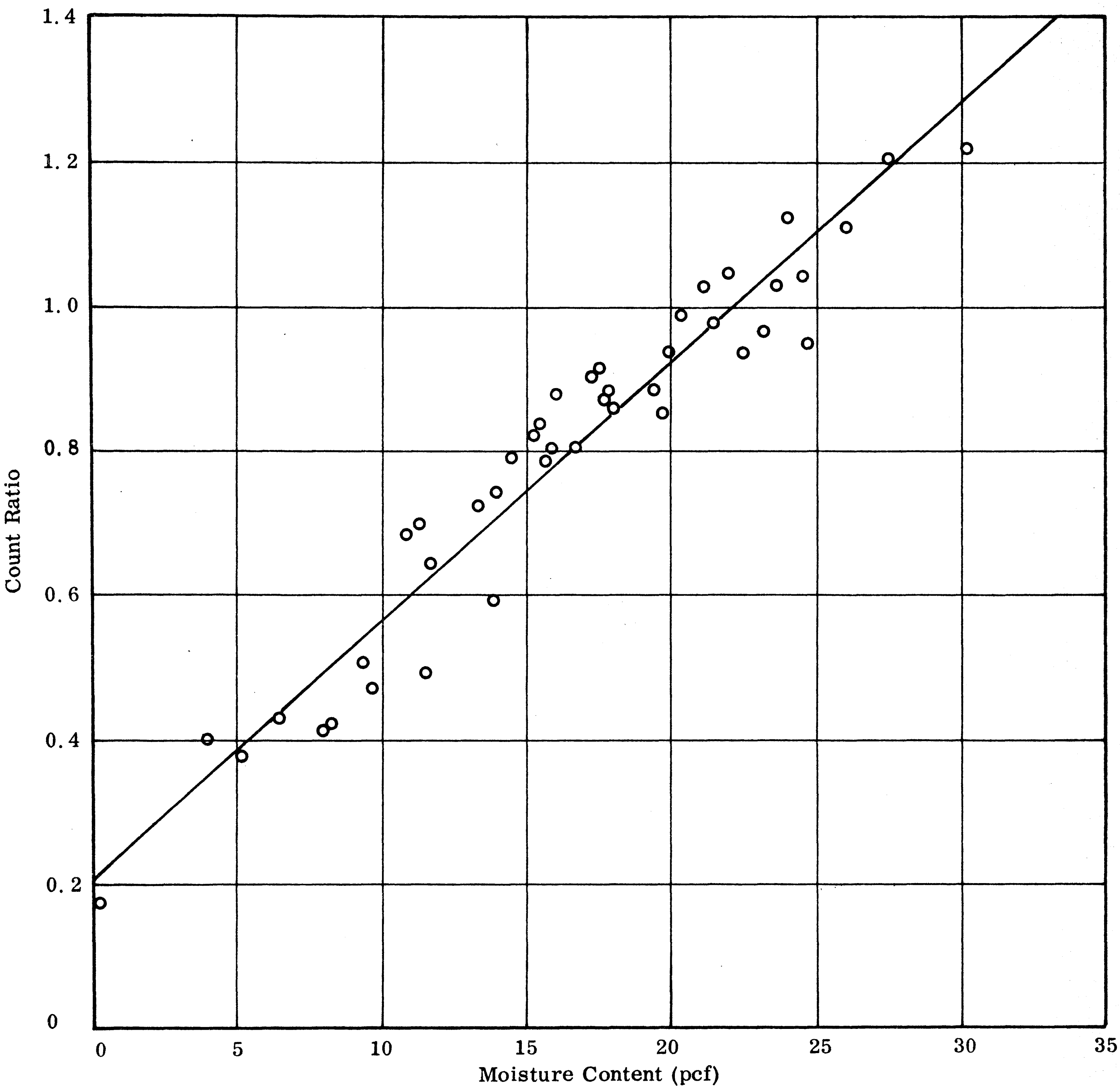

Figure 3. Single calibration curve for Model 2401 gage.

DISCUSSION OF RESULTS

In the Anday-Hughes study[2], various methods of analysis were used to determine if the data for the Model 227 gage could be divided into two groups. It was found that the data could be separated into two groups by three properties with the following limits:

1. Optimum moisture content — 18%;
2. Percent passing No. 200 screen — 48%; and
3. Percent sand — 30%.

The data collected in both studies with the Model 227 gage were combined and analyzed as in the previous study. The soils were first analyzed to see if they could be grouped according to their optimum moisture contents. By visual inspection the data points were separated into two groups. A separation point, if any, for the two groups was then determined. If a separation point could not be found, then the groups were redivided. After several trials it was found that the separation point by optimum moisture content was not 18% moisture as in the previous study, but was now 21% moisture. However, these two moisture contents may not be significantly different, since there are errors involved in the compaction tests and the nuclear tests. Since the optimum moisture content of a soil is known and available at the time of the field compaction test, then separation of the soils by their optimum moisture contents can easily be done in the field.

The separation of data by the other two properties, percent passing the No. 200 screen and percent sand, could not be done with the values determined in the previous study. However, the data could be separated into two different groups than those obtained when dividing at the 21% optimum moisture content level. Although the soils could be separated at different optimum moisture contents and by either percent passing the No. 200 screen or the percent sand, the standard errors were larger than those obtained using a separation based on the 21% level. Also, since this gage is no longer being manufactured or used in Virginia, the different groupings other than by a 21% optimum moisture content do not appear to be pertinent and will not be reported.

Besides the analysis for these three properties, the data were also analyzed for the following:

1. Atterberg limits,
2. maximum density,
3. gradation,
4. specific gravity, and
5. HRB classification.

However, no trends were indicated for these properties.

Since the soils could be separated according to their optimum moisture contents, it was felt that separation by the sources of the soils was possible. First, the soils were analyzed to see if they could be grouped by counties. As noted in the first study[2], no trend was indicated. Also, the soils were analyzed for separation into the three geologic areas of Virginia (Valley and Ridge, Piedmont, and Coastal Plain). As was the case for the grouping into counties, no trend was indicated.

Figure 3 is a plot of the data points for the Model 2401 gage. By visual inspection there seems to be no basis for grouping or separating data as with the Model 227 gage. In order to verify this finding, the same procedure used for the Model 227 gage with the different properties of the soils was used on the Model 2401 data. There was no indication that the data could be separated in any way by any of the properties. Therefore, a single calibration curve was determined for the Model 2401 gage. As shown in Figure 3, this curve has a standard error of 1.7 pcf. This standard error is considered to be reasonable, therefore, further work was not done.

The reduction of the standard error of a single calibration curve for the Model 2401 gage as opposed to the standard error of a single calibration curve for the Model 227 gage may be due to the following reasons:

1. The geometry of the gage;
2. the strength of the isotropic source;
3. the source type;
4. the detector system; and
5. other technological changes incorporated in the newer gage.

The new design also causes the slope of the calibration curve to be steeper than that of the curves of the Model 227 gage.

Figure 4 shows the two calibration curves determined for the Model 227 gage data and the curve provided by the gage manufacturers (dashed line).

In Virginia adjustments have been made with the Model 227 gage for high moisture soils in some cases. In other words, at times the manufacturer's curve has been shifted to suit the soil being tested. For soils with moisture contents greater than 21%, the manufacturer's curve was about 3 standard deviations (5 pcf) from the higher moisture curve determined in this study. However, for soils with moisture contents less than 21%, the manufacturer's curve does not vary greatly from the one determined in this study. At

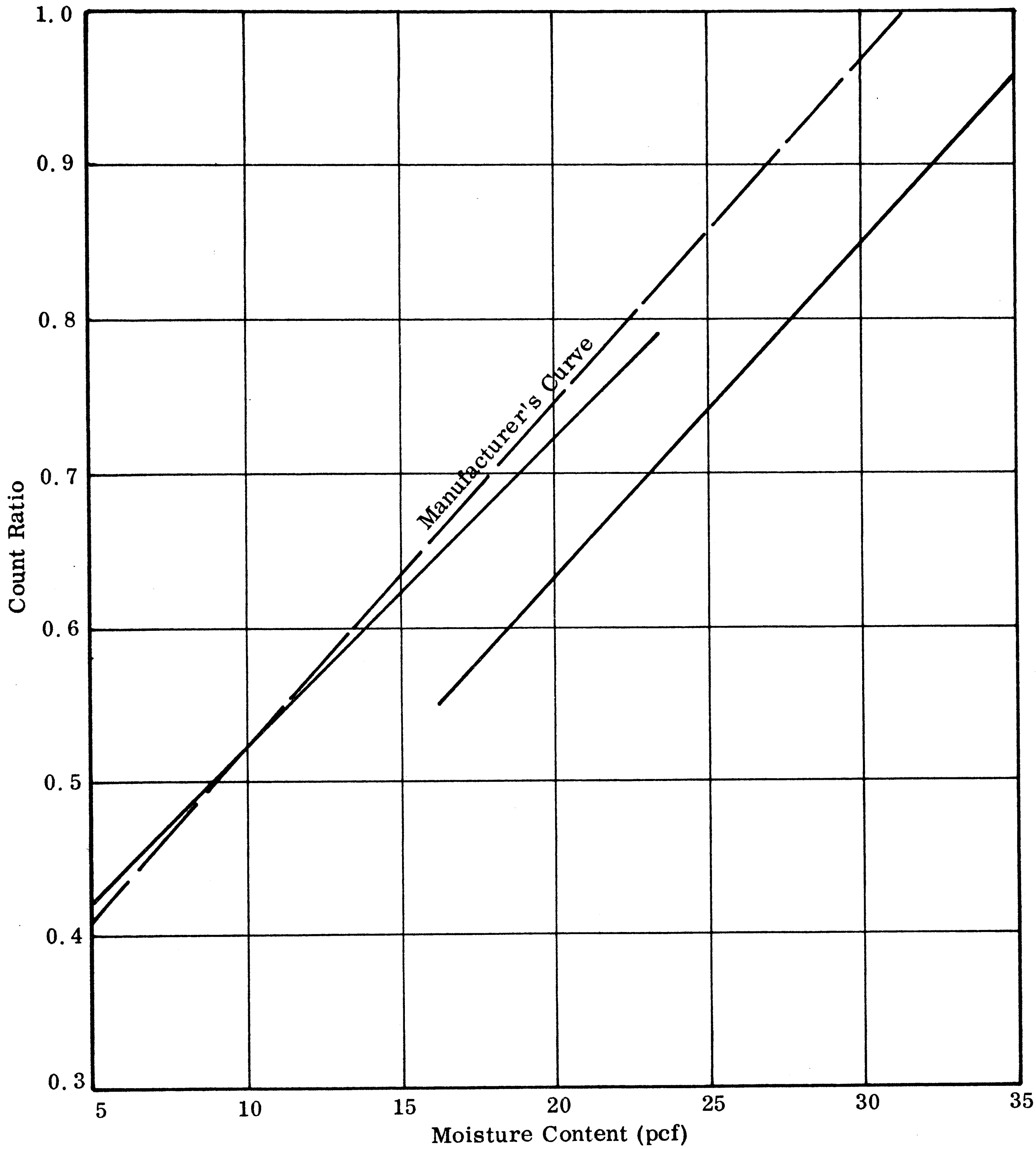

Figure 4. Calibration curves for Model 227 gage.

the upper limit of the lower curve the difference is about one standard deviation (1.5 pcf). As the optimum moisture contents of the soils decrease the difference between the manufacturer's curve and the lower curve decreases to zero at around 11 pcf. With moisture contents less than 11 pcf the curves diverge again, until the difference between the two is approximately 0.80 of a standard deviation (1 pcf) at zero moisture content.

Figure 5 shows the calibration curve (Figure 3) determined for the Model 2401 gage and the manufacturer's curve provided with the gage. In the figure it can be seen that the two curves roughly parallel each other and have a difference of approximately a half of a standard deviation (1 pcf), with the manufacturer's curve being higher.

CONCLUSIONS

The following conclusions can be drawn from the work to achieve the first two objectives of the study:

1. Two calibration curves with a linear response between the count ratio and the moisture content are necessary for accurate readings from the Model 227 gage.

2. The two calibration curves for the Model 227 gage are best divided by the optimum moisture content of the soil. The separation value of optimum moisture content is 21%.

3. The Model 2401 gage needs only one calibration curve and this produces a standard error of 1.7 pcf.

ANTICIPATED WORK

Since the Model 227 gage is no longer used in the state of Virginia, it will not be used in the development of the standards outlined in the last two study objectives. With this being the case, it is anticipated that the standards will be satisfactory for locating the single calibration curve of the newer gage. The first step in developing the standards will be to find the lower moisture standard. If success is achieved in this step, then development of the higher moisture standard will be attempted. Several standards that may be tried and the range of moistures that they may cover are: dry sand (0-1%), saturated sand (15-23%), sand mixed with different chemicals (0-30%), and any other product that may be available. If high and low moisture standards are developed, then an attempt will be made to develop a third standard to be used as a check on them. In this work, the first attempt will be to develop primary standards; if this attempt is unsuccessful then secondary standards will be investigated.

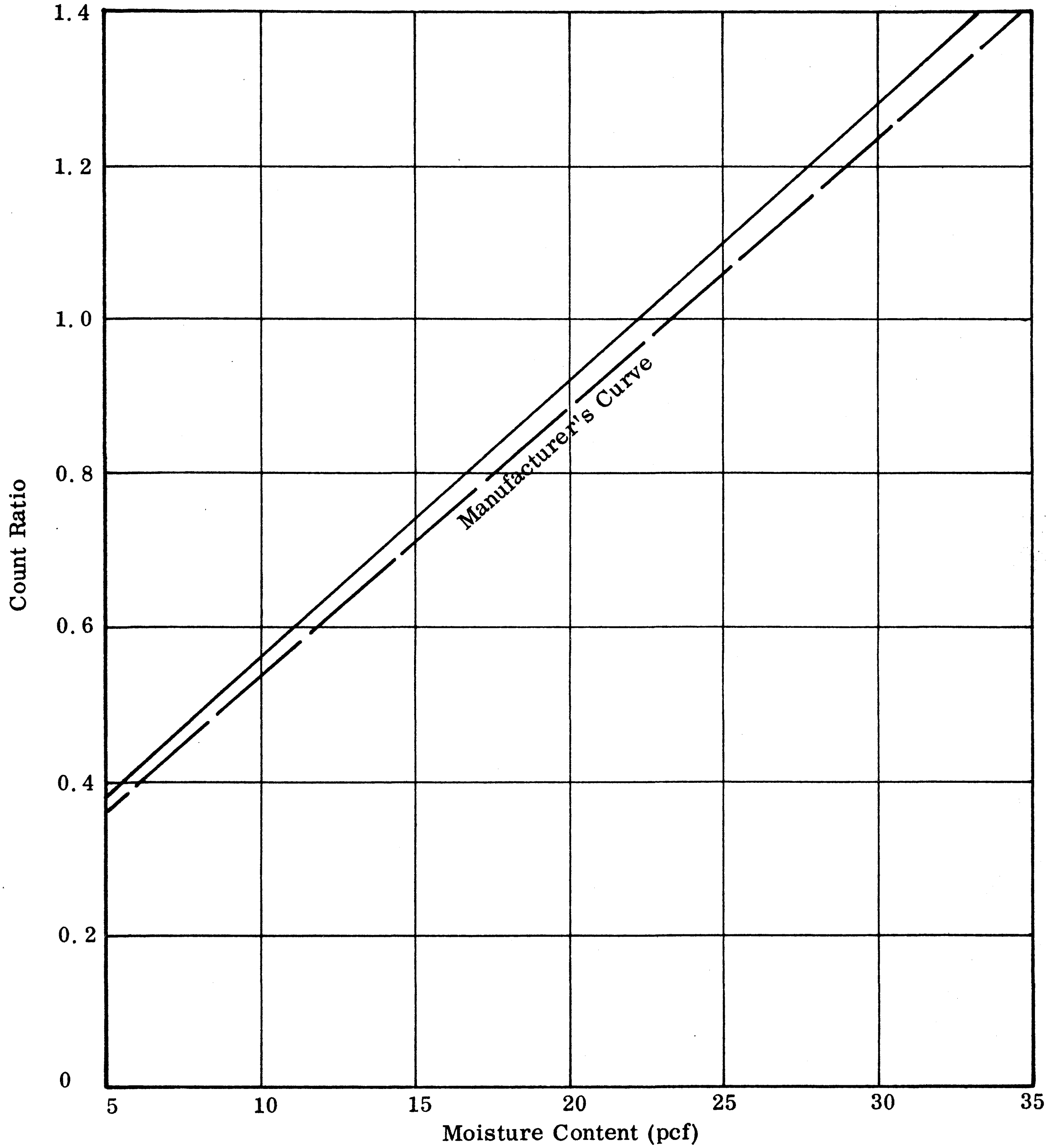

Figure 5. Calibration curves for Model 2401 gage.

In considering the many products that might be used for moisture standards many problems have to be overcome. Several problems are:

1. One must know the amount of moisture in the material that is being measured;

2. the material must be stable; and

3. it must be uniform.

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