An Evaluation of the Constant Dry Weight Compaction Method

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STATE OF VERMONT
AGENCY OF TRANSPORTATION
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ABSTRACT

There has been a need in the highway construction industry for a rapid and economical method of compaction testing. A method developed by the Ontario Department of Highways in the late 1960's is called the Constant Dry Weight (CDW) compaction test. It is a comparison of two volumes.

This study has examined the merits from a precision standpoint as well as a time saving method. A series of actual tests on a typical construction project were tabulated and analyzed as well as laboratory controlled comparisons. The Proctor method of test was used as a standard comparison. Side-by-side tests, molding comparisons and moisture estimations were considered.

The CDW method produces test results which are comparable to the Proctor Method. It has the additional benefit of not needing a complete evaluation (i.e. M-D curves, gradation, etc.) resulting in a cost savings.

INTRODUCTION

The success of a highway building program depends on a good quality control program of which embankment compaction testing is an integral part. The construction industry has, in recent years, developed new sophisticated equipment which cuts building time considerably. In view of this, new and faster methods of compaction testing have been developed, and still are being sought. The best known of these is the Proctor dry density method of measuring field density of the embankment material. Nuclear non-destructive methods have recently been developed to a high degree of accuracy. Any nuclear system is quite expensive initially to purchase, but it can save time and labor because of the number of tests which can be performed in a day's time.

A new method of promise has been developed in Canada by the Ontario Ministry of Transportation and Communication. It is called the Constant Dry Weight (CDW) method and is a variation of the Standard Proctor Test, AASHTO T-99, Method C. In the CDW test, the percent of compaction is determined by comparing the in place volume of a soil sample with the volume of the same sample in the Proctor mold after standard compaction ~~at about its optimum moisture. Since no moisture calculations are involved,~~ a considerable savings of time is realized in performing the test.

A project was undertaken to evaluate the constant dry weight method and to prove its worth as a rapid means of embankment testing. The sand cone Proctor test was used as a basis for comparison. The investigation was divided into five phases. The first phase was to tabulate and analyze the compaction values of a construction project, in the form of a frequency distribution, on which both the Proctor test and the CDW test were used.

The second phase involved pairs of the two compaction methods taken side-by-side in the laboratory. The third phase was to determine the accuracy of the dip stick wet density compared to the Proctor wet density. The forth phase was to analyze paired compaction tests of the Proctor method. The fifth phase was also done in the Central Lab and concerned the estimating of optimum moisture of various types of materials.

The comparison of the two methods requires an understanding of each in order to make an intelligent evaluation. A brief description of each method is included here with a step-by-step procedure.

THE PROCTOR METHOD

The standard of the industry is known as the Proctor dry density method which was developed by R. R. Proctor in 1934. It is based on dry unit weight of the material. A series of moisture-density control curves are constructed from representative materials which will be encountered on the project. They are used to determine the maximum density and optimum moisture of the test sample under consideration. In order to construct a moisture-density curve to comply with AASHTO designation T-99, it takes parts of three consecutive days, or longer, if a clay type soil is involved. Since no two samples of the same type ~~of material are exact duplicates, the~~ curves are only good guides. They truly only represent the sample of material from which they were developed. This test is, however, the most well known and has been successfully used throughout the industry.

A test hole is dug at the embankment site using standard equipment and the material returned to the mobile laboratory and the in place density calculated. After the moisture determination has been made, the material is compacted into a Proctor mold using a standard compactive effort. The molded unit dry density is determined as is its moisture content. These values are plotted on an appropriate moisture-density curve and the maximum dry density and optimum moisture are determined. These maximum and optimum values are related to the embankment values to calculate the percent compaction and the moisture condition. This complete process will take about forty-five minutes, depending on the distance from the site to the mobile lab.

The following is a general step by step description of the Proctor method. It is assumed that all equipment and sand has been calibrated and is ready for operation and all necessary moisture-density curves have been provided by the Central Laboratory.

1. Weigh sand jug, full.
2. Proceed to site and perform on site operations and return to lab.
3. Re-weigh sand jug to determine loss of sand.
4. Determine hole volume using the weight of lost sand and its density.
5. Weigh material taken from hole.
6. Determine its wet density.
7. Remove a moisture sample and weigh.
8. Dry moisture sample.
9. Re-weigh moisture sample to determine loss of water.
10. Calculate the percent moisture.
11. Determine the dry density of the in place material.
12. Compact the material into the Proctor mold using standard effort.
13. Weigh mold and soil and determine the weight of the soil.
14. Remove moisture sample from molded material and weigh.
15. Dry moisture sample.
16. Re-weigh moisture sample to determine loss of water.
17. Calculate the percent of moisture.

18. Determine the dry density of the molded material.

19. Choose an appropriate moisture-density curve and apply the molded dry density and its moisture percent to determine the maximum dry density and its optimum moisture.

20. Determine the percent compaction by dividing the field dry density by the maximum dry density.

21. Determine the moisture condition by comparing the optimum moisture to the field moisture.

THE CDW METHOD

The CDW Method of testing was developed as a rapid test for percent compaction of highway embankments. It could be called a volumetric test since it compares volumes, not dry densities or moistures. The equipment required for the test is the same as that for the Proctor method. The only addition is the measuring device called a calibrated dipstick. The dipstick is a six inch piece of plastic which has been divided on one side into units of one one-thousandth of a cubic foot when used with a Proctor mold. The other side of the dipstick is calibrated with the number of blows required to achieve maximum density based on hole volume. The divisions can be estimated to one ten-thousandth of a cubic foot without any difficulty. This dipstick is used to ~~determine the volume of material compacted in the mold.~~ A diagram of the dipstick can be found on page 21 of the Appendix.

The on site procedure is the same for this test as it is for the Proctor test except that slightly less material is taken for a sample from the embankment. This is necessary because all of the material must be compacted into the mold whereas for the Proctor method any excess material can be discarded. The completion of the test may be done at the mobile soils lab, or at the site. The material, after having been removed from the embankment, is adjusted to contain about the optimum amount of moisture and compacted into the Proctor mold. The compactive effort is determined from the volume of the hole. After the molding is completed, the volume of the compacted material is determined by use of the dipstick using four points around the mold and one in the center. The resulting average of these values is divided by the volume of the hole in the embankment; this is the embankment percent compaction.

The whole procedure can be done in about ten minutes or less if done at the site; if done at the soils lab, it of course, depends on the travel time.

The following is a general step-by-step description of the CDW method.

1. Weigh sand jug, full.
2. Perform on-site operations.
3. Re-weigh sand jug to determine loss of sand.
4. Determine hole volume using the weight of lost sand and its density.
5. Evaluate moisture condition and adjust to near optimum.
6. Compact material into Proctor mold.
7. Using the dipstick, determine the volume of material in the ~~mold.~~
8. Determine the percent compaction by dividing the volume of the material in the mold by the volume of the hole.

PHASE I

ANALYSIS OF CONSTRUCTION COMPACTION TEST RESULTS

A typical interstate highway construction project was chosen where both Proctor and Constant Dry Weight compaction testing methods were used at random throughout the season. The test values were tabulated into a frequency distribution with a one percent interval value as shown in Table II, page 9. The purpose of this distribution was to see if there was any similarity in the occurrence of passing and failing test values between the Proctor density method and the CDW method of compaction testing. The materials tested were mostly of a granular nature, although a fair number fell into the silt range. All the tests were performed by the same person which would remove any personal bias that could influence the resulting values. The embankments were all constructed in the standard manner using conventional compacting equipment. Moisture was not a problem since most of the embankments were made from dry, well drained materials.

All of the tests were performed at the mobile testing laboratory in order to minimize any inconsistencies in weighing and molding. The same field equipment was used in taking the tests as well as the same lab equipment. Standard Ottawa sand meeting ASTM designation C-190 was used and was calibrated regularly.

Test sites were not chosen in order to provide directly comparable test results. The choice of test sites was of a random nature and equal care was taken in the processing of each test. The two methods may or may not have been done at the same time or the same place; only as chance would have it.

There were a total of 791 Proctor tests and 595 constant dry weight tests performed. Table I on page 8 provides a breakdown of test results obtained from each of the methods in a comparative form.

TABLE I

	Proctor	CDW
Total Number of Tests in Frequency	791	595
Number of tests passing	757	574
Number of tests failing	34	21
Percent of tests failing	4.3	3.6
Mean	94.3	94.2
Standard Deviation	3.7	3.4

The soil types on this project were fairly uniform so it would be logical to assume that there is no variation due to soil types. Mathematical analysis shows that the mean of the frequency of pass / fail results does not differ significantly with test type. The standard deviations of 3.4 and 3.7 percent are in close agreement. These results compare favorably with the results of a study done by the Ontario Ministry of Transportation and Communications. The Ontario study shows that the CDW test produced a range of standard deviation of 2.3 to 2.5 percent while the standard Proctor results produced a range of 2.0 to 2.7 percent.[1] The ranges encompass standard deviations for three different soil types.

PHASE II

SIDE-BY-SIDE LABORATORY COMPACTION TESTS

As with any comparison testing the ideal is to have identical test conditions. In practical application this is difficult. To provide conditions as nearly identical as possible a container large enough accommodate two sand cones and plates, side by side, with an adequate quantity of soil was necessary.

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[1] R. SHONFELD, "The Constant Dry Weight Method - A No-Weighing Field Compaction Test," DHO Report No. RR 141, Ontario Department of Highways, (September, 1968) Table 4, P 17.

TABLE II

PERCENT OF TOTAL TESTS BY COMPACTION METHOD

Percent Compaction	Proctor	CDW
90%	11.9	15.9
91	11.4	7.6
92	8.7	9.5
93	10.6	10.5
94	10.4	10.8
95	9.6	10.0
96	7.7	9.0
97	6.6	8.1
98	7.8	7.1
99	5.2	5.9
100	4.7	2.2
101	1.0	0
102	0	1
103	1	1

A rectangular box was constructed of three-quarter inch marine plywood and coated with several layers of epoxy paint inside and out. The dimensions of the box were twelve by twenty inches and eight inches deep. Sturdy two by four inch handles were attached to the outside for lifting. The handles also reinforced the sides to prevent bulging when compacting the soil. A removable collar similar to that of a Proctor mold was made to fit over the top of the box.

A falling hammer arrangement on a vertical steel shaft was built to provide the compactive effort. A flat four by four inch by half inch steel pad was attached to the bottom of the steel shaft. A six inch pad was first used, but it did not transmit enough energy to the soil and proved to be cumbersome to operate. No attempt was made to weigh the hammer or calculate the amount of energy created.

The remaining equipment used was Standard Proctor testing equipment with the exception of a Fairbanks platform scale for weighing the full box of soil and a CDW dipstick.

The objective in using the box mold is to provide a container for the soil. The soil was compacted as uniformly as possible so that all areas were as close to the same density as possible. The soil was placed in the ~~box in five uniform layers and tamped with thirty-nine blows of the hammer.~~

The soil extended up into the collar and was leveled with a straightedge in a manner similar to the Proctor mold procedure.

In the beginning the blows were distributed evenly over the surface of the soil. It was subsequently discovered that the soil density was higher in the center of the box than on the edges, apparently due to the resistance of the sides of the box. The pattern of the blows was changed so that more effort was placed on the edges of each layer. This seemed to correct the problem. The thirty-nine blows was chosen because it put the percent compaction in the ninety percent range.

A quantity of soil of different types was collected sufficient to fill the box with some left over. It was thoroughly mixed at low moisture content in order that it be uniform throughout. Samples were taken for a Proctor moisture-density curve and for classification. Just prior to molding, the moisture content was raised to near optimum as determined by the moisture-density curve. Once the desired moisture content was obtained, it was entered on the work sheet during the test procedure. A moisture determination was made for each test in the set. It was found that the material did dry out somewhat during the day's testing.

After each set of tests was completed, the box was emptied, the soil thoroughly re-mixed and the process repeated.

Several soil types were used in the study. These were chosen at random and were typical of the soils in the state which would be encountered during a construction project.

All data obtained from the testing was tabulated on work sheets. This included the box wet density, wet and dry density from both the CDW and Proctor methods, the molded wet density of both methods, the dry density of each method and of prime interest, the percent compaction.

There were two main concerns of this phase of testing. The first was a comparison of the percent compaction determinations obtained from each of the test methods and the second was the reliability of the "dipstick" method of measuring mold volume.

Pairs of tests were run and the difference in percent compaction determination were analyzed. The evaluation, broken down by soil type, of these differences is shown in TABLE III following.

TABLE III

Soil Type	Mean Difference	Std. Deviation	# of Samples
A-4 Silt	0.45	1.67	23
A-1-b Sand	-0.32	1.44	28
A-2-4 Mix	0.40	1.35	25
A-2-4 Sand	0.85	1.71	36
A-2-4 Silty Sand	-0.06	1.19	15
Total Combined Samples	0.45	1.67	127

Figure 1 is a graph of the percent compaction results obtained by the Proctor method versus the results obtained by the Constant Dry Weight Method.

The best-fit regression has been plotted along with the confidence limits.

PHASE III

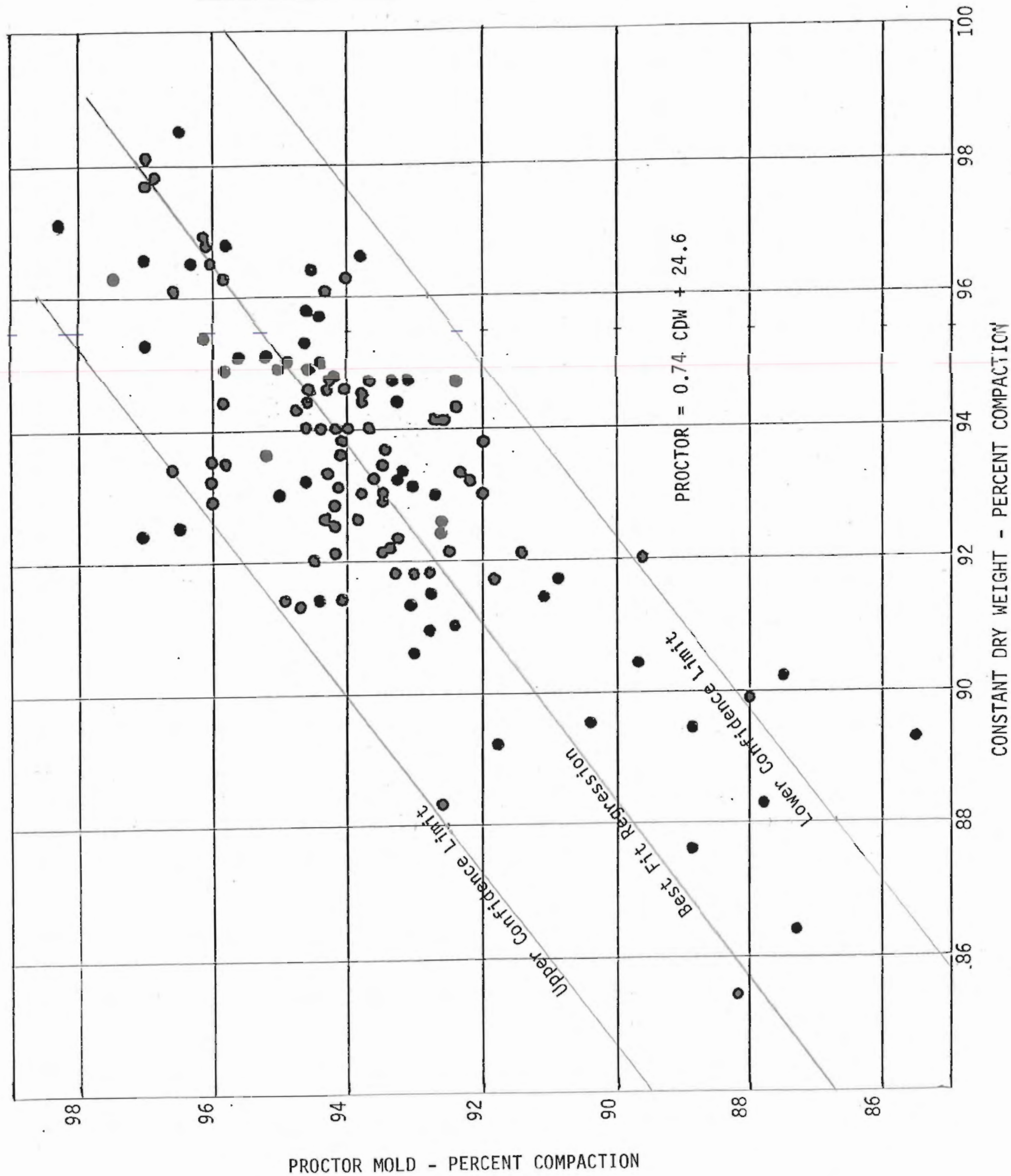
WET DENSITY COMPARISON

The results of the differences obtained from the wet density moldings of the Proctor method versus that of the CDW method are listed in the following table:

Soil Type	Mean Difference	Std. Deviation	# of Samples
A-4 Silt	-0.56	1.09	21
A-1-b Sand	-1.92	1.92	28
A-2-4 Mix	-0.03	1.24	25
A-2-4 Sand	-1.22	1.62	36
A-2-4 Silty Sand	-0.43	1.06	14
Total	-0.95	1.62	124

Mathematical Analysis of the results revealed the following. The difference between soil types is statistically significant. Although the mean differs significantly from zero and there is a statistical difference between soil types, the differences in the means are experimentally insignificant.

According to ASTM D698, the single operator precision for molded wet density is 1.9% of the value obtained. This is a greater figure than the amount by which confidence in the table above or the difference between soil types.


PROCTOR = 0.74 CDW + 24.6
Upper Confidence Limit
Best Fit Regression
Lower Confidence Limit
CONSTANT DRY WEIGHT - PERCENT COMPACTION
100
98
96
94
92
90
88
86
PROCTOR MOLD - PERCENT COMPACTION
98
96
94
92
90
88
86

PHASE IV

PAIRS OF PROCTOR TESTS

The differences between standard Proctor job and progress compaction tests were analyzed for 206 samples. These tests are done side-by-side, simultaneously as part of an assurance testing program. A standard deviation of 1.8 was obtained which is 4 times the average difference between the Proctor and the CDW percent compaction, as shown on page 12.

PHASE V

OPTIMUM MOISTURE ESTIMATION

A small project was set up in the Central Laboratory to determine how near optimum the moisture of a soil sample could be estimated by an experienced compaction inspector. The only criteria allowed were the ability to observe by handling, squeezing, and shaking. Four samples of different materials were air dried and each person adjusted the water content until they felt that the material had reached its optimum. The soils ranged from an A-4 silt to an A-1-b coarse sand.

A total of eighteen separate tests were performed by a group of five experienced compaction personnel. Arrangements were made to see to it that the results were not known until all the testing had been performed. This removed any influence of one person's opinion on another. A standard moisture-density curve was constructed for each material and was used to establish the optimum moisture of each.

It was demonstrated that eighty-three percent of the estimates of these persons were within two percent of optimum. The results also showed that slightly over half of the test results were on the dry side of optimum. Of the estimates which were less than optimum, the average difference was 1.8 percent; those above optimum averaged 0.6 percent.

The overall average difference from optimum moisture for all samples was -0.9 percent.

DISCUSSION

The frequency and occurrence of pass / fail results on an actual construction job was compiled from test reports. There was no significant difference in the frequency of pass / fail results attributable to test method.

In general it appeared that an experienced compaction testor is able to estimate optimum moisture levels for various soil types within a reasonable degree of accuracy.

The wet density comparison established that the use of the dipstick for volume determination is feasible and accurate. This point is essential to the use of this test.(CDW)

The lesser number of procedural steps in the CDW vs Proctor tests allows fewer opportunities for error.

The 21 steps in the Proctor method do not include the steps necessary to construct the moisture-density curve at the laboratory. It must also be noted that the sample submitted for a moisture-density curve may not exactly duplicate the embankment being tested. It is not possible to have a curve for each and every different soil on a project and it is often necessary to "find a curve that fits" a particular sample. A material is fitted to a curve by using its molded moisture-density relationship and apparent soil type. Time does not permit a complete analysis of a material from an embankment. The analysis is done visually and its accuracy depends upon the judgement and experience of the inspector.

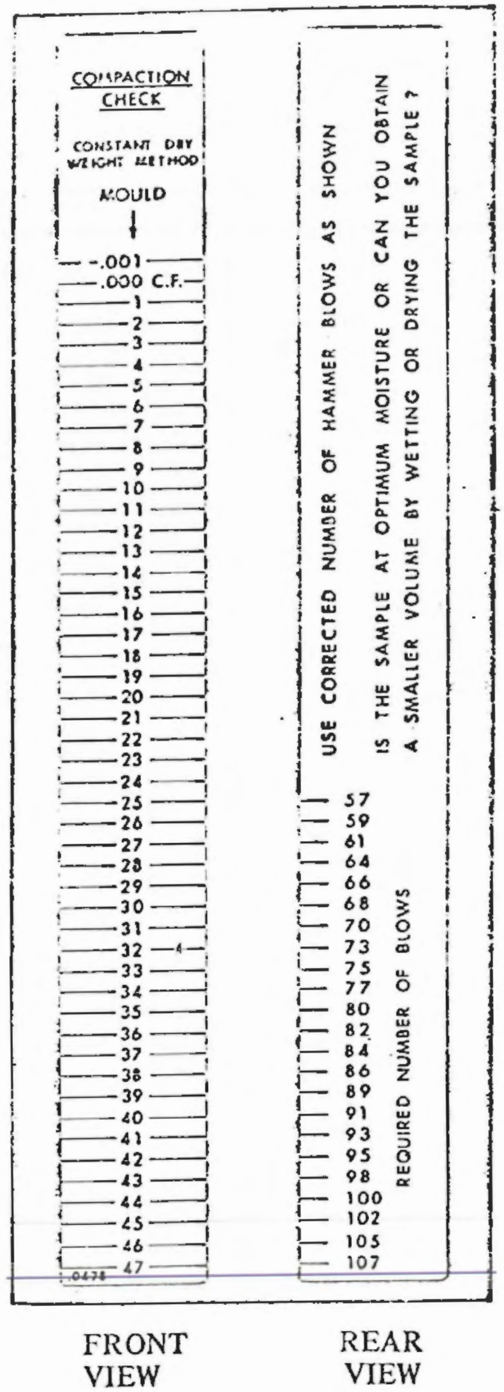
The CDW method involves the comparison of one volume from an embankment with a standard volume for comparison. It is dependent upon the skill and experience of the operator to correctly estimate "optimum moisture".

There is a substantil saving of time possible with CDW due partially to the fewer steps and partially because all operations can be done at or near the test site thus affording the operator greater opportunity to supervise the filling operation and reducing travel time.

CONCLUSION

From this study it is apparent that the CDW test is a viable alternative to the Standard Proctor Method when employed by an experienced inspector.

A P P E N D I X



THE CALIBRATED DIPSTICK

Soil Type:
% Stone:
Sand:
Silt:
Wet Density:
Wt. of Soil:

STATE OF VERMONT
DEPARTMENT OF HIGHWAYS
SOILS LABORATORY

COMPACTION TEST WORK SHEET
CONSTANT DRY-WEIGHT METHOD

C.D.W. RESEARCH

TEST BY ______________________ DATE ______________________

Percent	105	100	97	95	93	90	87	85	83	80	77
% x weight											
Pan											
Pan & Soil											
No. blows per layer	26+2	25	24+1	23+1	22+2	22+1	22	21+1	20+1	19+2	19
Dipstick readings: 1											
2											
3											
4											
5											
Total of readings											
Average											
Mold Correction											
Corr. reading											
Wet Density											

VERMONT AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH DIVISION

PROJECT:_______________ CONTRACTOR:_______________

TEST BY:_______________ DATE:_______________

1. Test No.									
2. Station									
3. Offset									
4. Depth Below Subgrade									
5. Soil Type									
6. Wgt. Sand Jug (before)									
7. Wgt. Sand Jug (after)									
8. Wgt. Sand Used (6-7)									
9. Cone Correction									
10. Net Sand in Hole (8-9)									
11. Sand Density									
12. Net Hole Volume (10÷11)									
13. Dipstick Readings 1.									
2.									
3.									
4.									
5.									
14. Total of Readings									
15. Aver. Volume of Readings									
16. % Compaction (15÷12)									
17. Moisture Condition									

State of Vermont

AGENCY OF TRANSPORTATION

MATERIALS DIVISION - SOILS SUBDIVISION

COMPACTION TEST WORK SHEET

PROJECT ______________________________ CONTRACTOR ______________________________

TEST BY ______________________________

In-Place Density

1. Test No.				
2. Wgt. Sand Jug (Before)				
3. Wgt. Sand Jug (After)				
4. Wgt. Sand Used (2 — 3)				
5. Cone Correction				
6. Net Sand in Hole (4 — 5)				
7. Sand Density				
8. Net Hole Volume (6 ÷ 7)				
9. Wgt. Soil + Sample Can				
10. Wgt. Sample Can				
11. Wgt. Soil (9 — 10)				
12. Wet Density (11 ÷ 8)				
13. Wgt. Plus ¾" + Sieve				
14. Wgt. Sieve				
15. Wgt. Plus ¾" (13 — 14)				
16. % Plus ¾" (15 ÷ 11) (100)				
17. Corr. Wet Density				
18. 100 + % Moisture*				
19. Dry Density**				

In-Place Moisture

1. Test No.				
2. Can No.				
3. Wgt. Can & Soil & Water				
4. Wgt. Can & Soil (Dry)				
5. Wgt. Can				
6. Wgt. Water (3 — 4)				
7. Wgt. Soil (4 — 5)				
8. % Moisture (6 ÷ 7) (100)				

Report Data

1. Test No.				
2. Station				
3. Offset				
4. Depth Below Sub-Grade				
5. Curve No.				
6. Soil Type				
7. Maximum Density				
8. Optimum Moisture				
9. Field Moisture Condition				
10. % Compaction				

Moisture-Density Check Point

1. Test No.				
2. Wgt. Mold & Soil				
3. Wgt. Mold				
4. Wgt. Soil (2 — 3)				
5. Can No.				
6. Wgt. Can & Soil & Water				
7. Wgt. Can & Soil (Dry)				
8. Wgt. Can				
9. Wgt. Water (6 — 7)				
10. Wgt. Soil (7 — 8)				
11. % Moisture (9 ÷ 10) (100)				
12. Dry Density***				

* % Dry Moisture from No. 8 of In-Place Moisture Test

** Dry Density = (Corr. Wet Density ÷ No. 18) (100)

*** Dry Density = (No. 4 × 3000) ÷ (100 + No. 11)

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