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DIVISION OF RESEARCH AND DEVELOPMENT

"Control of Subbase Compaction: A Progress Report"

by

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ABSTRACT

The Test Strip Method has been proposed to replace the current method specification for subbase compaction control in New Jersey. This research was initiated to determine the feasibility and desirability of adopting the proposed method. The first year's study analyzed both methods with the following conclusions. The proposed Test Strip Method yields improved subbase compaction compared to the current method. Neither method, however, consistently achieves 100 percent of the standard Proctor density that literature recommends is necessary to prevent the pavement distress associated with further compaction under traffic. Also, the Test Strip procedure requires a considerable amount of field work even on small simple projects.

Key Words: Nuclear Density Moisture Gauge, Compaction, Subbase, Gradation, Density, Soil Aggregates

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CONTROL OF SUBBASE COMPACTION: A PROGRESS REPORT

1.0 INTRODUCTION:

This report presents the first year's results of a three-year study designed to determine the applicability to New Jersey conditions of a method of soil compaction control referred to as the "Test Strip Method."

2.0 BACKGROUND:

2.1 Existing Specification for Compaction Control: New Jersey presently employs a method specification for controlling compaction of granular subbase. Under these provisions a minimum of 5 passes is required for "approved" pneumatic tire rollers and a range of 2 to 5 passes is specified for "approved" vibratory rollers. These requirements do not change regardless of the thickness, type or source of subbase materials.

The exact number of passes to be used with a particular subbase material and roller is determined by the Project Resident. The choice of passes and the adequacy of the resulting compaction is thus a function of the Resident's knowledge of equipment and material and the extent of any (optional) density tests performed.

2.2 Density Standard: Once a roller pass requirement is set for subbase on New Jersey projects, no sampling of the density subsequently achieved is required.* Indeed, there is no required standard to which any such tests could be compared.

*In small areas where hand compactors must be used, a minimum of 95% of standard Proctor density is required, conformity being based on the sand-cone methods.

In marked contrast, nearly all states compare field compaction results to a laboratory standard. As might be expected, however, there is no single test which is accepted by all. According to a 1967 North Carolina report, of the many density tests available as a standard, the two used most often are the standard Proctor (ASTM D698 or AASHO T-99) and modified* Proctor (ASTM D1557 or AASHO T-180) (2,10).**

Several studies have been conducted by various agencies to determine the amount of subbase compaction required during construction to prevent further densification under traffic. For this work some agencies, including the New Jersey Department of Transportation, removed the surfaces of in-service roads and compared the field density of the underlying soil with the achievable standard Proctor. Another agency investigated the relationship between the amount of pavement deflection under traffic and the degree of compaction in the subbase. All these studies proved a need for a minimum density of 100 percent of the standard Proctor for optimum road performance . (3,4,5)

Further, nearly half of the states require a minimum of 100 percent of the standard Proctor in their specifications or the material must be rerolled or removed and replaced, depending on the severity of the deficiency.(1)

2.3 Nature of the Test Strip Control Method: The Test Strip Method is a modification of the density control system developed by the State of Virginia and is based on the use of nuclear devices.(1) The "Test

*The modified Proctor uses a greater compactive effort and thus yields a greater density.

**The numbers in parenthesis indicate the appropriate references for the information given.

Strip" referred to in this method is simply a small area of subbase on a project on which nuclear moisture-density testing is performed after each pass of the roller. The maximum density obtained from this Test Strip provides a standard for controlling the compaction of other sections of the project which are built with the same thickness, type, and source of subbase material, and the same roller. In practice, this requires subdividing the rest of the project into small areas known statistically as "lots" of subbase. Changes in the variables used in the Test Strip will require a new density standard (i.e., a new Test Strip). In this regard, while certain variable changes are of obvious significance (e.g. roller or material source changes), the significance of subtle changes in materials gradations remains to be determined. Based on a consultant's recommendation,this Department's specification group proposed that New Jersey adopt the Test Strip Method as a standard for controlling compaction of both subbase and embankment materials. The initial consultant's proposal had two alternate procedures - one using the optimum density from the Test Strip as the standard by which to judge the remainder of the project and the other using a standard laboratory test as the target density. These two procedures are now a subject of research.

It appears that a third alternate has been incorporated in the final draft of the forthcoming revised State standard specifications. In this method a Test Strip is performed only for the purpose of enabling the Project Resident to make an informed choice of the number of passes to be made by the roller. No follow up acceptance testing will be required.

3.0 EQUIPMENT:

New Jersey presently uses seven nuclear density gauges for soils and bituminous testing, several of which were used to collect the moisture and density data of this first year's research. All of the devices were purchased from Troxler Electronic Laboratories, two being the older 1401 models and the other five are the newer 2401 models. In subsequent years data will be obtained primarily using a 2401 gauge recently acquired by the Division of Research.

These gauges are calibrated on standard blocks yearly and the data is provided in a tabular form. The moisture calibration range is from 0 to 40 pcf in 0.25 pcf increments while the density calibration range is from 70 to 160 pcf in 0.5 pcf increments.

Testing in accordance with ASTM D3017 for determining the moisture of soil aggregates indicates that the maximum allowable standard deviation associated with the precision and accuracy of the nuclear gauge moisture measurements are 0.3 pcf and 1.0 pcf respectively(2).

Testing in accordance with ASTM D2922 for determining the density of soil aggregates indicates a maximum allowable standard deviation associated with the precision of nuclear gauge density measurements is 1.25 pcf(2). Accuracy testing (which reflects composition errors as well as precision) indicates a maximum allowable standard deviation of 5.0 pcf for a single measurement. However, the accuracy of the density readings in this work might reasonably be expected to be better than this allowable (i.e., within 3.75 pcf rather than 5 pcf at 95% level) for the following reasons.

First, all density readings made for this research were with the gauge in the direct transmission position because it is the most accurate method in terms of precision and composition errors. The precision is better by a factor of 2 to 1* over the backscatter method and the composition error is also decreased. The exact reduction of error due to composition effects depends on the gauge being used, the material being measured, and the depth of the measurement. Therefore, some readings may be more accurate than others because of the particular conditions but all single readings should be within 3.75 pcf. Secondly, by averaging several single readings, as in a lot, the measurement uncertainty is reduced even further.

4.0 RESEARCH APPROACH:

This research is divided into a laboratory phase and two concurrent field phases. A discussion of the nature of each of these phases and a summary of work to date is as follows:

4.1 Field Studies of the Current Control Method:

The first field phase is directed toward determining the level of subbase compaction being achieved by the current method specification and thus in essence answering the question "How well are we currently doing?" The procedure involved here was simply to obtain the average of five random nuclear density readings taken in an area of subbase recently rolled where the number of passes had been established by the Project Resident. To date, eleven sets of these readings have been made and recorded with the corresponding standard Proctor for each project material.

*This is stated in the manufacturer's instruction manual and verified during the calibration of Department gauges.

4.2 Field Studies of the Test Strip Method:

The second, major, field phase is directed toward answering the question "How well will the Test Strip Method adapt to New Jersey conditions?" Toward this end, four projects under construction were selected to simulate the proposed Test Strip specification. A 300 foot long area of mainline subbase freshly placed and graded was set aside at the beginning of the project for the Test Strip. Then, each time the roller made a pass over the area five nuclear density readings were taken. The average density of the five readings was plotted against the number of passes to form a graph. The optimum density and corresponding optimum number of passes was then determined from this graph. These values were appropriate only for similar circumstances on that project.

On each of the projects selected for application of the Test Strip Method, five follow-up density readings were taken on an area of mainline having the same conditions as the original Test Strip. Subsequent test samples or "lots" varied in length from 300 feet to 800 feet. The average of the five readings from each lot was then compared with the standard densities determined by laboratory and field tests. Lot data was collected on three of the four projects selected. This sample consisted of eleven lots from one project, five lots from another, and two from the third.

4.3 Laboratory Studies of Density Standards:

In addition to the field testing on the Test Strip, three different laboratory density tests were performed on the material from that area in an attempt to establish an appropriate density standard to which the Test Strip optimum density could be compared. These laboratory tests included the two general Proctor methods (ASTM D698 Method C and ASTM D1557 Method D) and a Relative Density test (ASTM D2049). This latter test uses vibration as the compactive effort instead of impact as the other two methods do.

In addition to the field and laboratory test data mentioned, roller information and material gradations were recorded for all tests on conventional and Test Strip projects. Data was also gathered from the files to determine the typical characteristics of subbase on current projects; i.e., gradation, thickness, and source variability.

5.0 RESULTS:

Since only one year's research is complete, the amount of data being analyzed is limited. Each of the various types of subbase are analyzed on a combined basis in this report to determine general results and trends. As more information is collected, individual subbase types will be analyzed separately.

5.1 Projects Controlled by Present Method Specification:

The eleven sets of readings gathered on projects controlled by the present method specification are listed in Table 1. As indicated, the measured field density on these projects ranges from 81.6 to 100.6 percent of the standard Proctor and averages 92.4 percent. On only two of the projects did the measured field density reach the 100 percent Proctor level indicated as necessary for optimum performance of the roadway structure.

PRESENT SPECIFICATION DENSITIES

TABLE 1

Subbase Type	Average Field Density	σ of Field Density	Standard Proctor	Field Density is Significantly Lower	% Standard Proctor
1B	118.0	3.34	136.9	Yes	86.1
1B	118.7	5.36	123.8	No	97.4
1B	113.9	1.62	123.8	Yes	92.0
1C	123.8	1.36	123.6	No	100.1
1C	107.6	2.05	117.0	Yes	91.9
2A	123.6	3.59	138.1	Yes	89.5
2A	114.5	1.17	125.2	Yes	91.4
2A	120.0	2.71	131.1	Yes	91.5
5A	131.8	5.25	131.0	No	100.6
5A	117.6	2.01	144.0	Yes	81.6
5A	133.0	1.38	141.5	Yes	93.9

Average = 92.36

$\sigma_{\text{Ave.}}$ = 2.50

It is to be noted, however, that as in any testing process, there is variability in field and laboratory density measurements. Thus, while most of the field densities were apparently lower than the corresponding standard Proctor, the inherent testing variability must be taken into account and this difference proven statistically. The results of a statistical significance test (the student's "t" test performed at the 95% confidence level) are shown in Table 1. These tests indicate that the apparent "low" level of density is indeed significant. That is, all but three field densities were significantly lower than the standard Proctor and two of those three were at least equal so that only one which appeared to be lower than the Proctor density was not.

5.2 Projects Employing Test Strip Method:

5.2.1 Comparison of Initial Test Strip Densities to Laboratory Densities: The four sets of density values from the projects employing the Test Strip Method are listed in Table 2. None of the projects achieved 100% of the standard Proctor as literature recommends.

The same significance test used with Table 1 was also applied to this data. In two of the four cases the maximum test strip density was significantly lower than the standard Proctor.

Because of the higher compactive effort specified for the modified Proctor test, the density achievable by this test is always higher than the density of the standard Proctor test on the same soil. Similarly, the maximum density achievable by the relative density

TEST STRIP DENSITIES

TABLE 2

Route	Subbase Type	Max. Test Strip Density	σ of Test Strip Density	Standard* Proctor	Test Strip Density is Significantly Lower	% of Standard Proctor
I-280	1C	135.0	2.02	136.3	No	99.0
N.J. 15	1C	130.4	1.91	133.3	No	97.8
N.J. 55	1B	121.2	3.32	127.5	Yes	95.0
I-80	1C	117.2	2.06	123.8	Yes	94.7

Average = 96.62

σ Ave. = 1.85

*The standard deviation associated with the testing process for determining the standard Proctor values is estimated to be 0.70 percent. An explanation is in the appendix.

test on the same material is also higher than the standard Proctor density, generally being comparable to the modified Proctor density. It follows, then, that if 100 percent of the standard Proctor test was not attained with New Jersey conditions, then 100 percent of the other two tests was not attained either.

5.2.2 Comparison of the Initial Test Strip Densities to the Present Specification: To answer the question, "Is the density achieved by the Initial Test Strip higher than the present specification density?", a student's "t" test at the 95 percent level was performed. The comparison of the average percent standard Proctor values from Tables 1 and 2 indicate that the densities from the Initial Test Strips are significantly higher than the densities on projects using the present specification.

5.2.3 Comparison of Lot Dessities to Initial Test Strip Densities: Table 3 lists the average densities from each lot measured. Relative to the maximum Test Strip values the average lot densities range from 87.2 to 103.2 percent with a mean of 96.7 percent. Of the 18 lots measured, eleven are lower than the 98% minimum recommended by ASTM D2940 (2)*. Tested at the 95% confidence level, five of the eleven lots on the I-280 project were found to be significantly lower than the corresponding Initial Test Strip. All of the five lots from the N.J. 15 project were significantly lower, whereas neither of the lots from N.J. 55 were lower. On the whole just over half of the lots are signficantly lower than the Initial Test Strip value. In general, then, the densities obtained on the tested projects do not compare favorably to the achievable density indicated by the Test Strip.

*This minimum reflects a two percent allowance for the contractor's protection.

LOT DENSITIES

TABLE 3

Route	Average Lot Density	Lot Density is Significantly Lower	% of Max. Test Strip	% of Standard Proctor
I-280	130.1	No	96.4	95.4
	127.9	Yes	94.7	93.8
	117.8	Yes	87.2	86.4
	121.9	Yes	90.3	89.4
	126.2	Yes	93.5	92.6
	130.9	Yes	97.0	96.0
	136.1	No	100.8	99.8
	134.2	No	99.4	98.4
	132.9	No	98.4	97.5
	135.8	No	100.6	99.6
	134.3	No	99.5	98.5
			Average = 96.16%	Average = 95.22%
			σ Ave. = 3.16	σ Ave. = 3.13
N.J. 15	121.4	Yes	93.1	91.1
	125.8	Yes	96.5	94.4
	124.0	Yes	95.1	93.0
	126.0	Yes	96.6	94.5
	125.9	Yes	96.5	94.4
			Average = 95.56%	Average = 93.48%
			σ Ave. = 1.95	σ Ave. = 1.91
N.J. 55	124.2	No	102.5	97.4
	125.1	No	103.2	98.1
			Average = 102.85%	Average = 97.75%
			σ Ave. = 2.66	σ Ave. 2.52
	GRAND AVERAGE		96.74%	95.02%
	σ		2.77	2.72

5.2.4 Comparison of Lot Densities to Present Specification Densities: Relative to the standard Proctor values the average lot densities range from 86.4 to 99.8 percent with a mean of 95.0 percent. All of these values are also below the 100 percent minimum suggested by literature. The mean of the Test Strip lots is significantly higher than the mean value from the projects using the present specification at the 95% confidence limit. With regard to individual projects the means from the I-280 and N.J. 55 lots are significantly higher than the projects with the present specification while there is no significant difference for the N.J. 15 project.

6.0 ESTIMATED TESTING WORKLOAD ASSOCIATED WITH THE TEST STRIP METHOD:

6.1 General:

While the desirability of adopting the Test Strip Method is related to adequate compaction results, the feasibility of this method is related to the work load. The amount of work involved is directly dependent on the number of Test Strips and lots which must be performed on each project. Influencing this number is the variability of New Jersey subbase gradations. This material's variability also leaves open for speculation the appropriateness of using a single value either Test Strip or Proctor as the target density for a large area.

Listed below are the several proposed criteria for establishing a new Test Strip for the method under investigation.

1. A different roller is used.
2. A change in the source of material.
3. A change in material lift thickness.
4. A significant change in material gradation from the same source.
5. The maximum of 10 lots for a given Test Strip has been reached.

The following discussion will be directed toward the points listed above in an effort to estimate the possible number of Test Strips that could be performed on one project.

6.2 Materials and Equipment Variability on New Jersey Projects:

First, most construction projects have more than one roller on the site and many times these rollers are not the same make and model, thus necessitating a Test Strip for each roller used.

Next, recent records of New Jersey construction projects indicate that the average number of sources from which one subbase type may be supplied is four--not including any blending of materials as is commonly done.

Third, the plans of recent construction projects show an average of two different thicknesses for every type of subbase. Only type 1A material had one thickness specified on the projects where it was used. Importantly, some of the other subbase types had as many as four thicknesses on a single project.

Finally, although it is not finalized at this point as to what amount of change in gradation is significant,much work has been done relating achievable density with gradation (particularly on the No. 4 sieve). This work points out the importance of determining what Proctor density should be associated with each lot. In other words, use of only one Test Strip for as many as 10 lots may be overly optimistic.

The graph in Figure 1 is a compilation of the curves established by many researchers, including New Jersey Department of Tranportation, showing the relationship between No. 4 gradations and the standard

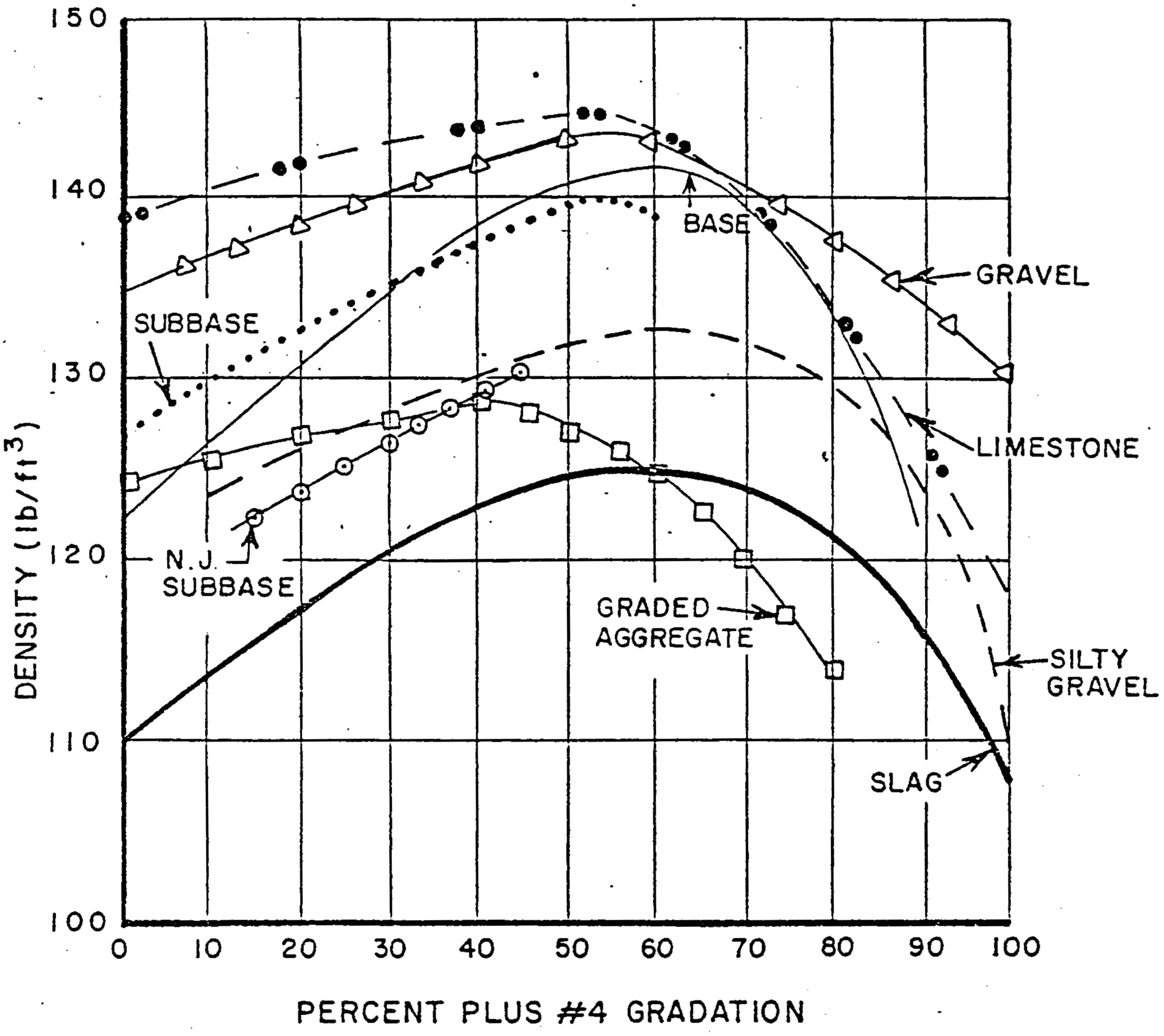

Figure 1: Influence Of #4 Gradation On Proctor Values For Different Types Of Materials (From Ref. 6,7,8,9,12)

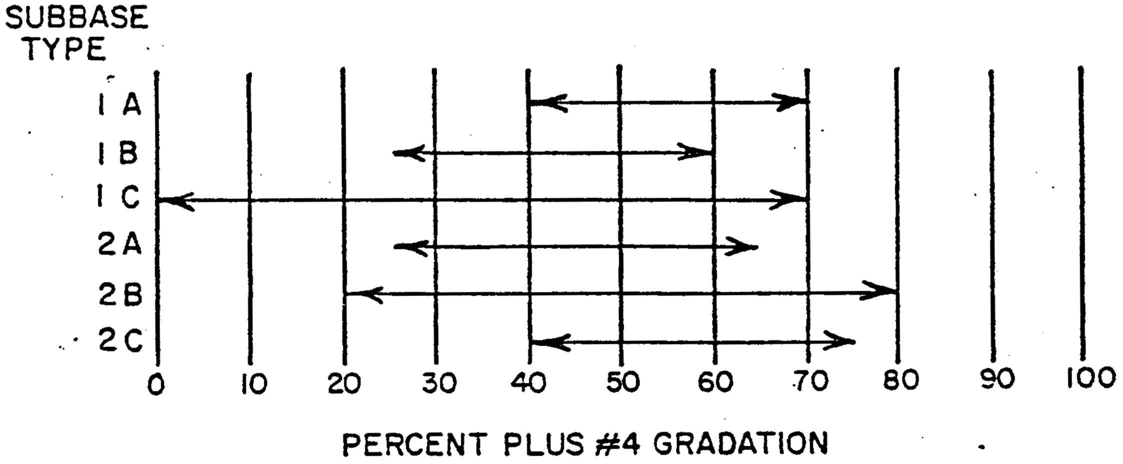

Figure 2: Allowable Subbase Gradation

Proctor densities of various materials (6,7,8,9,12,14). The No. 4 gradation band in the New Jersey specifications is broad (Figure 2) and when projected onto the graph in Figure 1 shows the possible changes in density for each type of material. The ascending slopes of the curves vary from 1/10 to 3/10 pounds per percent change in gradation. Descending slopes of the curves vary between 1/10 and 7/10 pounds per percent change in gradation.

ASTM D2940 recommends ± 10 percent as the largest #4 sieve size band for subbase. Theoretically if a standard Proctor was performed on material from both extremes of this band the densities could vary by as much as 6 pounds (20% x 3/10 lb/%) on the ascending side of the curve or 14 pounds (20% x 7/10 lb/%) on the descending side or any lesser amount at the arch of the curve.

New Jersey's bands are much broader, as already shown, and the possible Proctor values can vary over a wide range. In fact, the project files prove that some sources are capable of spanning most of the allowable No. 4 sieve range.

The allowable variation in New Jersey subbase soil gradations make it difficult, if not impossible, to decide when the material in a lot is no longer representative of the Test Strip material. In that light, only a change in the type of subbase will be considered as cause for a new Test Strip for this preliminary analysis of the testing work load. There are usually only two or three subbase types on a project.

Considering the points enumerated, a possible number of Test Strips that might be performed on one project include 2 for rollers, 4 for sources, 2 for thickness, and 3 for subbase types. A total of 11 Test Strips per project might be performed not including any combinations or permutations of the preceding points. If 1/2 day is allowed to perform each Test Strip, over one week's total work is involved for each project not including the follow-up densities in the lots.

To estimate the work load for the necessary follow-up testing of lot densities, let us assume that a typical project is 2 miles long and a lot is 1,000 feet long. In this case the possible number of lots for one lift of subbase would be twenty (ten for each roadway). Since the lots may be completed at different times, density testing could possibly involve part of twenty separate days. A project with only two lifts, one Test Strip for each, may have a total work load of over four weeks. In view of the existing limited number of nuclear gages and operators, if several projects require testing at a given time,a very significant problem would be presented. While not specifically a part of this work, an important ramification of the preceding should be noted. That is, recall that this Test Strip Method has also been recommended for embankment material. In view of the substantial work load involved for subbase which has a controlled gradation and limited number of lifts it certainly seems possible that applications of the Test Strip method to other more highly variable embankment materials, could entail an overwhelming testing volume.

7.0 ANTICIPATED FUTURE RESEARCH:

The primary nuclear density gauge to be used for all future testing is the 2401 model purchased by the Division of Research. The use of a single instrument will reduce the variability presently incurred by using several different machines. The composition error associated with measurements can be more precisely determined for a single gauge and, thus, further increase the accuracy.

It is important to recall that the lot densities could not consistently reach 100 percent of the maximum Test Strip value. In fact, eleven of the eighteen lots measured were less than the recommended 98 percent - some were considerably less. Unsatisfactory results were also obtained with respect to the percent of Proctor value for each lot. None of the lot densities were able to reach 100 percent of the standard Proctor that was established using Test Strip material. These poor results in the lots could have two possible causes - inadequate compaction or a change in material. It is essential to try to separate these two variables for analysis and thus to determine the source of the generally inadequate compaction.

Considering the ability of New Jersey subbases to span the entire allowable range of gradation and considering the Proctor values associated with such wide ranges, it is apparent that further research is required to detect possible material changes which significantly affect achievable density. To determine these changes, additional laboratory testing is planned. At the time of the Test Strip a large enough sample of material will be obtained to perform a series of standard Proctor tests to establish a density-gradation curve similar to those shown in Figure 1. On one of the subsequent lots, perhaps the fourth or fifth, another large sample will be obtained and a similar density-gradation curve will be established. The relationship between these two curves is critical.

To illustrate, consider the situation where the testing results from the Test Strip material is represented by the curve A in Figure 3 and the testing results from the lot material is represented by curve C. Because of the great difference between the curves, it is evident that even though the source of material and the allowabe gradation have not changed, the characteristics of the material have changed. For this case it would be a mistake to use a single Test Strip Proctor density as the target value for all the lots on a project. That is, the only way to determine the appropriate Proctor value for any of the intermediate lots is to perform individual laboratory tests for each one.

Now consider the other situation illustrated in Figure 3 where the test results from the Test Strip material is represented by curve A and the test results from the lot material is represented by curve B. These two curves are essentially the same which means the character of the material has not changed. An appropriate Proctor value for any intermediate lot can be obtained from the curve by knowing the gradation. In this case, where it is established that there is no change in the characteristics of the material, and the adequacy of compaction can be directly determined any inadequacy of compaction can be attributed to the compaction process per se (i.e., compactive effort and/or moisture conditions).

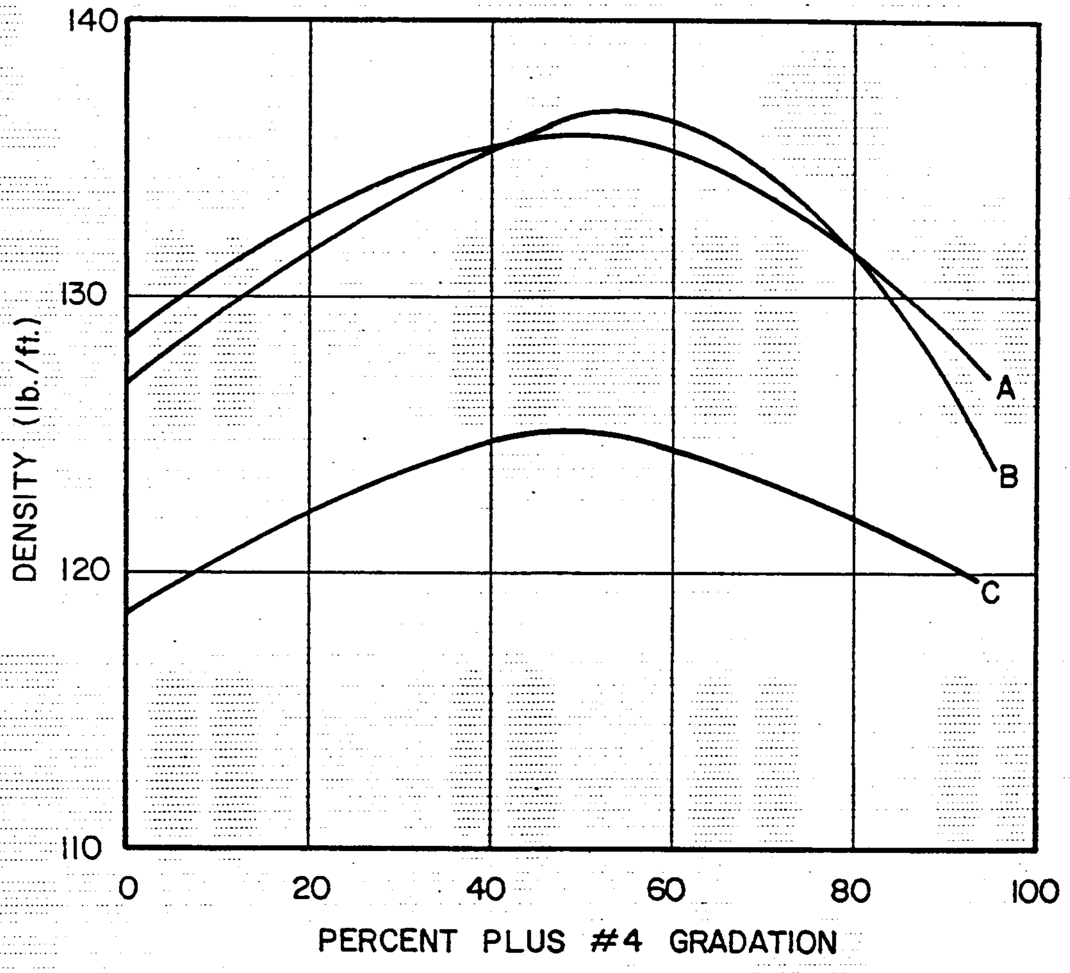

FIGURE 3: Theoretical Density-Gradation Curves

8.0 SUMMARY:

This first year's study of subbase compaction control involved the investigation of the present compaction specification and the proposed Test Strip Method. Eleven sets of readings were gathered on projects controlled by the present method and four projects were selected to simulate the Test Strip Method. On these four projects the proposed procedure was followed beginning with the Initial Test Strip and continuing through the subsequent lot densities. Also included were several standard laboratory density tests. To assist in the evaluation of the proposed method, a preliminary estimate of the testing work load necessary for field personnel was made.

Following is a brief summary of the results:

1. All of the maximum Test Strip densities and the subsequent lot densities were less than 100 percent of the standard Proctor values. Over half of the lot densities were significantly lower than the Test Strip maximum.
2. Nearly four-fifths of the densities obtained on projects using the present specification were significantly lower than 100 percent of the standard Proctor.
3. The relative Proctor densities from the Test Strips and lots were significantly higher than the values from projects using the present specifications.
4. New Jersey subbase compaction could not consistently achieve 100 percent of any of the three standard laboratory tests performed but was closest to the standard Proctor values (ASTM D698).

5. For a simple hypothetical project two miles long with only two lifts of subbase and two Test Strips, the total work load could be over four weeks for field materials personnel. A more complicated project with several types of subbase, sources of material, rollers, and lift thicknesses could involve two weeks of work just to perform the required Test Strips.

9.0 CONCLUSIONS:

It can be concluded from the first year's research that the Test Strip Method yields improved subbase compaction compared to the present method of control. Neither method, however, consistently achieves 100 percent of the standard Proctor value which literature indicates is necessary to prevent further subbase densification under traffic.

Three different standard laboratory density tests were performed on the subbase materials. As a result it was determined that the most appropriate laboratory test for density comparisons is the standard Proctor (ASTM D698).

A large amount of field work is involved with the proposed Test Strip Method. It is estimated that over one month's actual field time could be required on even a simple project. The amount of work involved for embankment material, one can imagine, would be much greater than for subbase which is a controlled material.

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APPENDIX

Lab Variability

The only data available to determine the variability of the standard Proctor on New Jersey subbases performed by departmental employees was obtained during this first year's research. The standard Proctor value for each of the four projects employing the Test Strip Method was performed by two groups. By pooling the variances of these four sets of tests, a standard deviation of 0.70 was established. Further research will determine a standard deviation with more confidence.