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SD2000-02-F

# Soil Density Target Values

## Study SD2000-02
## Final Report

Prepared by
South Dakota State University
Department of Civil and Environmental Engineering
Brookings, SD 57007

May 2001

## DISCLAIMER



## ACKNOWLEDGEMENTS

This work was performed under the supervision of the SD2000-02 Technical Panel:

| | | | |
|---|---|---|---|
| Brian Hines | Office of Research | Ron Dahme | Mitchell Region |
| Daris Ormesher | Office of Research | Mike Boland | Aberdeen Region |
| Kip Johnson | Rapid City Area | Ralph Linder | GeoTek, Inc. |
| Brett Hestdalen | FHWA | Bob Longbons | Materials and Surfacing |
| Vernon Schaefer | South Dakota State Univ. | Bud Schweigert | Schweigert Construction |

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16. Abstract


The compaction of soil in embankments, subbase or base course layers is one of the most important aspects of road construction. In order to ensure the soil is placed as specified and with uniformity, frequent testing of the compacted soil is necessary. This testing requires the in-place dry density of the soil to be obtained along with the soil moisture content. The values are then compared to a specified standard, typically a percentage of standard Proctor density, and optimum moisture content (OMC) to determine if the sample meets the required specification.

The South Dakota Department of Transportation (SDDOT) presently uses the Ohio Typical Moisture Density Curves to establish target moisture density values. This method of repeatedly establishing the target values can be a time consuming process that limits the time available for inspectors to perform other duties. Additionally, the ability to complete the required number of tests with the equipment and personnel available becomes challenging for the inspectors. In many cases it could require up to an hour to complete a single one point determination and moisture density test. The length of time required to complete each test means contractors are not obtaining timely feedback on the quality of their work. In the event a test fails, the contractor may be required to perform a significant amount of rework, causing delays and increasing costs.

The research is focused on three issues: determining the suitability of current SDDOT soil and granular materials testing policies and procedures, developing recommendations for improving efficiency while maintaining or improving quality of soil and granular compaction testing policies and procedures, and to develop recommendations for a training program to address all procedural changes.


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# CHAPTER 1 EXECUTIVE SUMMARY

## 1.1 Introduction

The compaction of soil in embankments, subbase or base course layers is one of the most important aspects of road construction. In order to ensure the soil is placed as specified and with uniformity, frequent testing of the compacted soil is necessary. This testing requires the in-place dry density of the soil to be obtained along with the soil moisture content. The values are then compared to a specified standard, typically a percentage of standard Proctor density, and optimum moisture content (OMC) to determine if the sample meets the required specification.

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The research proposed herein is focused on three issues: determining the suitability of current SDDOT soil and granular materials testing policies and procedures, developing recommendations for improving efficiency while maintaining or improving quality of soil and granular compaction testing policies and procedures, and to develop recommendations for a training program to address all procedural changes.

## 1.2 Purpose

The overall objective of this research was to increase the efficiency of SDDOT inspectors in performing field compaction testing so that less time is spent on each individual compaction test thereby providing results in a more timely manner and freeing up personnel for other inspection duties. To meet this overall objective the following sub-objectives have been identified:

1. Determine the suitability of SDDOT current soil and granular materials compaction testing policies and procedures in an effort to reduce or eliminate the need of one-point testing.
2. Develop recommendations for improving efficiency while maintaining or improving quality of soil and granular testing policies and procedures.
3. Develop recommendations for a training program to address all procedural changes.

## 1.3 Approach

In the spring of 2000 a study of the problem was undertaken by the Civil and Environmental Engineering Department at South Dakota State University (SDSU). The study reviewed procedures used in the state of South Dakota as well as other states to determine the methods used to evaluate soil compaction in the field. A series of tests were performed on a number of soil samples to determine how well they matched the Ohio family of curves. Additionally, new and alternative testing technologies were reviewed for their potential towards soil testing. Based on this work, a series of recommendations were developed to increase the efficiency of soil density testing in the field.

## 1.4 Significant Findings

The following are the most significant findings from this study:

1. New technologies may provide radically different means of testing soil compaction in the near future, resulting in faster results, and increased testing, at no increase in labor requirements.
2. 93 % of the states surveyed use a density based compaction specification.
3. All states using density based compaction specifications use either a family of curves or 4 point determinations to establish target values.
4. 88% of the states surveyed use nuclear gauges for soil density testing.
5. In South Dakota, a significant portion of the testing time is spent in transit from the test site to the field laboratory.
6. Of all surveyed states, South Dakota has one of the most rigorous testing programs for pipe backfill.

## 1.5 Conclusions

Based on the findings of this research, a series of conclusions may be drawn with regard to soil density testing in the state of South Dakota.

One of the primary objectives of this research was to determine if there were any density based testing methods in use by other states that would be more efficient than the methods currently used in the state. Based on the survey results there are no such methods.

A brief investigation was conducted to review non-density based testing methods for compaction inspection. This review determined that new methods have been developed that may eliminate some of the problems associated with density based testing and establishment of target values. Of these methods, the Humboldt Stiffness Gauge appears to be the device that is most commercially viable. This device has been tested by various agencies around the country in recent years, and in 2001 a Federal Highway Administration (FHWA) sponsored pooled study will provide a large scale field trial. It is suggested that in the coming years this device, or one similar, will replace density based testing of compacted soils.

No other density based procedure used by other states show any potential for significant increases in efficiency and it may still be a few years before new technologies that are not density based find widespread acceptance. Therefore, in the interim period, efficiencies must be achieved through modification of existing procedures. These efficiencies can come through the following actions: reducing transit time between sampling locations and testing locations, reducing frequency of testing of pipe backfill soils, allowing use of microwave ovens for determination of moisture contents, and make increasing use of existing nuclear gauges. Finally, it should be stated that the inspector needs to have a more visible presence on site, and current procedures limit that.

## 1.6 Recommendations

<u>**Recommendation One**</u>: Avoid significant changes to the SDDOT Materials Manual.

It is the opinion of the author that the means by which we specify soil compaction will change within the next 3 to 10 years. Advances in electronic instrumentation and computing hardware and software are allowing the development of new equipment at reasonable costs. If that opinion is accepted, then the state must look at positioning itself to begin to transition to these new methods. However, as with all changes, the state must not abandon a system that has provided us with properly compacted soils until we are certain the new methods will provide equal or better results.

If the state believes that within the next three to five years new methods will be available to test soils, then significant changes to the existing procedures should not be made. This is because it may not be prudent to totally change a system before the 2001 construction season only to totally change it again three to five years later. Significant changes potentially require obtaining many pieces of new equipment, total rewriting of all testing specifications, complete retraining of all employees, and familiarizing contractors with these new methods. To go through this process twice in a three to five year period could be potentially wasteful and create more confusion than progress.

At the same time, the success of stiffness based design and testing methods is still unknown. The potential for success has clearly been documented, but the results of the FHWA pooled study must be available to make that determination.

Therefore, current soil density testing in South Dakota must be streamlined in an effort to allow technicians more time to complete their tasks. Modifications to the Materials Manual should be developed that reduce the time devoted to soil testing without radically changing existing procedures. This would help alleviate the immediate problem, while allowing the state some time to determine if the new technologies will become reality in the near future.

**Recommendation Two**: Inspectors should have vehicles equipped with density kits.

On many jobs the inspector is away from the work site because of the transit time from the test site to the field laboratory. The use of a vehicle equipped with the necessary testing equipment would allow the inspector to remain on site nearly full time and still accomplish the necessary testing. A total cost for the equipment is not given because many of the DOT labs have much of this equipment on hand. Additionally, the cost may depend on how the agency wishes to conduct the tests (i.e. sand cone vs. rubber balloon, stove-top moisture vs. speedy, etc.) Digital and mechanical scales are available that meet the accuracy requirements of the Materials Manual. Digital scales are rechargeable for field use. This recommendation provides more continuous observation of the contractor, while also providing a significant time savings to the inspector. In some cases, the time to travel to and from the field laboratory is equal to the time spent actually testing the soil. This is a repeat recommendation from SD 91-05 "Essential Testing and Inspection Levels." In the nine years since that recommendation was made, personnel reductions may justify reconsideration of this recommendation. The technical panel for project SD 91-05 stated that the idea had been tried but that the rough terrain on which the vehicles operated could cause damage to the equipment. Michigan DOT uses self-contained kits exclusively and did not report this as a problem.

**Recommendation Three**: Reduce the frequency of density testing of pipe backfill.

It is not adequate justification to make a recommendation based solely on the fact of what other states specify. However, the significance of the difference between the frequency of pipe backfill testing required in South Dakota and that of other states does suggest that South Dakota may be overtesting these soils. Because the rationale behind the development of the testing frequencies used in SD was not discovered, it is difficult to establish how that standard was arrived at.

It is recommended that the minimum testing frequency of pipe backfill be the same as what is used for the layer into which the pipe is being placed. Therefore if the pipe is being placed in the embankment, it must be tested at the frequency specified for embankment soils. In addition, a test should be done on the soil at the base of the trench prior to placement of the pipe or any bedding material. Once again, this is a minimum testing frequency that provides the inspector a clear picture of what is necessary to achieve the desired compaction in the field. If subsequent observations of the operation indicates adequate compaction is not being achieved, the inspector is certainly able to test over and above the minimum requirement. By adopting this testing frequency, a reduction in the number of one-point tests is also achieved.

**Recommendation Four**: Allow use of microwave oven for moisture content determination.

The use of the microwave oven for moisture content testing of soils is specified by ASTM D 4643. Because of the widespread presence of microwave ovens in laboratory trailers, this method should be considered for use.

**Recommendation Five**: Develop a field guide for earthwork testing.

Although many engineers appear to feel comfortable with the SD Materials Manual, many inspectors and interns suggested that the size and wording of the manual made it an intimidating and sometimes confusing document. The Materials Manual primarily contains the frequencies and procedures for field and labs tests for soils, aggregates, asphalt, concrete, and miscellaneous materials. Much of the manual does not apply to field testing of earthwork. A smaller and concise pocket type manual, like used by the Ohio DOT, may find widespread use and acceptance in the field. This handbook contains sections on General Soils Information, General Earthwork Construction, Moisture Control and Testing, Compaction of Soils, Compaction Testing of Soils using a Nuclear gauge and Sand Cone, and a section on earthwork Inspections, Tests, Reports, Controls and Calculations. The manual provides simple step by step instructions on each of the topics. The manual would be developed to be a supplement (but not a replacement), to the Materials Manual to be used in the field.

**Recommendation Six**: Disseminate training materials to all DOT offices conducting field testing.

For the personnel who are unable to attend the annual or refresher training for soil testing, standardized materials should be widely available to all personnel conducting soil testing on DOT projects. All workbooks and presentation materials should be available to every DOT employee conducting soil testing. This would provide materials for review sessions by full time employees at the local offices and provide training aids for summer interns. Additionally, this would provide valuable information to contractors who are required to perform testing to state specifications.

**Recommendation Seven**: Increase use of existing nuclear density gauges.

The use of nuclear density gauges for soil testing varies from region to region. Although the use of the nuclear gauge does not change minimum test frequency or requirement for one-point determinations, it does allow for additional testing. Also, the project must require enough testing be performed to allow for proper determination of density and moisture correction factors. Once the target value has been established, the nuclear gauge can provide moisture density results much faster than the sand cone or rubber balloon method. Use of the nuclear gauge would allow for additional testing over and above what is currently being accomplished. Certain regions within the DOT do not get acceptable results with regard to moisture contents from the nuclear gauge, and that contact with the manufacturer has not resolved the issues. The source of these problems may be related to instrument calibration or use in soils that contain bound hydrogen. Calibration problems cause the output to be inconsistent. Proper readings in soils with bound hydrogen should be obtained with application of a correction factor. Operator training materials used in SD are consistent with those used in other states. The resolution of these issues would lead to increased confidence, and use, of the nuclear gauges.

**Recommendation Eight**: Obtain assessment of the Soil Certification Course to maintain quality instruction that meets student needs.

Personnel who have attended the SDDOT Soil Certification Course should be encouraged to provide feedback on what portions of the course are relevant to their work. In many cases evaluations are given at the end of a class. In addition, a follow up evaluation could be sent to the students at the end of the summer construction season asking their opinions on how the class was beneficial to them and if there was additional material that needed to be covered. Those responses could be evaluated prior to the offering of the next Soil Certification Class so that changes could be made before the start of the next class.

**Recommendation Nine**: Conduct extensive evaluations of the Humboldt Geo Gauge.

During the 2001 construction season, the SDDOT has chosen to participate in the FHWA pooled study to evaluate the Humboldt GeoGauge™. This device, if successful, could be the tool that allows the state to eliminate the most burdensome and time consuming tasks related to testing of compacted soils. The state should use the device to the maximum extent possible this summer in a series of side by side tests with existing methods to determine the effectiveness, time savings, applicability to all South Dakota soils, training, and support. From this extensive use, the state could decide if this device is suitable for use. This way the state could forge ahead without having to rely solely on the results of the pooled study, whose results may not be available in time to make revisions and decisions prior to the 2002 construction season.

**Recommendation Ten**: Use existing state data to determine the validity of the Ohio family of Curves.

Of the 10 soils tested as part of this research, three were not represented within the allowable standards by the Ohio family of curves. Because this research used a limited set of test data, conclusions as to the validity of the Ohio curves can not be drawn at this time. If a significant number of 4-point curves are available from the materials engineers within the State, then this data should be collected and used to evaluate the validity of the Ohio curves for South Dakota, or, if necessary, develop a new family of curves.

# CHAPTER 2 PROBLEM DESCRIPTION

## 2.1 Problem Statement

The compaction of soil in embankments, subbase or base course layers is one of the most important aspects of road construction. In order to ensure the soil is placed as specified and with uniformity, frequent testing of the compacted soil is necessary. This testing requires the in-place dry density of the soil to be obtained along with the soil moisture content. The values are then compared to a specified standard, typically a percentage of standard Proctor density, and optimum moisture content to determine if the sample meets the required specification.

The South Dakota Department of Transportation (SDDOT) presently uses the Ohio Typical Moisture Density Curves to establish target moisture density values. This method of repeatedly establishing the target values can be a time consuming process that limits the time available for inspectors to perform other duties. Additionally, the ability to complete the required number of tests with the equipment and personnel available becomes challenging for the inspectors. In many cases it could require up to an hour to complete a single one point determination and moisture density test. The length of time required to complete each test means contractors are not obtaining timely feedback on the quality of their work. In the event a test fails, the contractor may be required to rework a significant amount of work, causing delays and increasing costs.

This research project was focused on three issues: determining the suitability of current SDDOT soil and granular materials testing policies and procedures, developing recommendations for improving efficiency while maintaining or improving quality of soil and granular compaction testing policies and procedures, and to develop recommendations for a training program to address all procedural changes.

These issues were investigated by developing a complete understanding of current SDDOT policies and procedures. A survey of other State DOT's and federal agencies was also conducted to determine how they address all aspects of compaction testing, including training. With this background, recommendations for improvements in efficiency, while maintaining or improving quality were developed. The resources necessary to implement these changes are also determined, in terms of equipment and training to personnel.

## 2.2 Background Summary

The use of soil as a construction material requires that its properties must be modified to develop the necessary engineering properties for performance. This is typically done by modification of the soil through compaction, modification of the water content, chemical stabilization, and/or alteration of the soils' gradation. Compaction, the densification by the application of mechanical energy coupled with modification of the water content, is the primary method for improving soils.

To ensure the soil is modified as required to meet the necessary engineering requirements, contractors must place the soil in a manner that meets specifications. These specifications may be method specifications, which instruct the contractor exactly how to place the soil, or end-product specifications, which specify some property the placed material must meet. Typically, most soil compaction specifications are end-product specifications. In most cases, the requirement is that the compacted soil be placed at a density and moisture content that meets some percentage of a standard (typically a specified dry density and moisture content for a specified compaction effort).

The goal in obtaining satisfactory long-term performance of a constructed fill for highway applications is to ensure that soil provides adequate stability. This stability must be achieved across the entire constructed fill, which requires uniformity in density throughout the fill. The achievement of this goal requires competent testing and monitoring during construction. The typical soil density test is a destructive test, meaning some of the placed soil is removed for testing. Because of the time required for destructive testing, it is both difficult and expensive to conduct a sufficient number of tests for a statistical analysis of results. In many cases, the volume of soil tested is a small percentage of the total fill (typically 1 part per 100,000) (FHWA, 1990). However, the benefits of good compaction are substantial and the consequences of poor compaction severe.

The requirement for the one-point Proctor test stems from the potential for the type of soil placed to change over the course of the project. If the borrow source was absolutely consistent over the project, then only one Proctor curve would be necessary for that material. But as the material changes, so does the maximum dry density and optimum moisture content. Because of this problem, a one-point Proctor may be specified for each density test. To eliminate this requirement, some agencies consider a visual inspection of the material to be adequate as the technicians familiarity with the soils used on the project increases. If the soil is recognized as one they have a valid Proctor curve for, then only the density test is required.

Clearly, the methods available for soil testing may provide some increase in efficiency over current methods used by the DOT. The rubber balloon (volumeter) measures the size of a hole created during density testing directly, which is faster then the indirect sand cone method. Also, the rubber balloon doesn't require calibration, eliminates the weighing step, as well as elimination of the recovery of the sand process typically performed as part of the sand cone test. Additionally, it is not sensitive to construction vibrations.

Microwave moisture content testing is typically faster than the stove top method and has the added advantage of being ASTM approved. In some cases, SDDOT technicians and interns are performing stove top moisture tests even though they have a microwave in the lab shack.

Visual inspection of the soil may eliminate the frequency of one-point Proctors, and use of the nuclear density gauges may also increase testing frequency and yield virtually instantaneous results.

In summary, alternative methods exist that may be more efficient than the methods currently used by the SDDOT. The investigation of these methods and their application to the SDDOT soil density inspection program were the focus of this research.

# CHAPTER 3 OBJECTIVES

## 3.1 Defined Objectives

The overall objective of this research was to increase the efficiency of SDDOT inspectors in performing field compaction testing so that less time is spent on each individual compaction test thereby providing results in a more timely manner and freeing up personnel for other inspection duties. To meet this overall objective the following sub-objectives have been identified:

1. Determine the suitability of SDDOT current soil and granular materials compaction testing policies and procedures in an effort to reduce or eliminate the need of one-point testing.
2. Develop recommendations for improving efficiency while maintaining or improving quality of soil and granular testing policies and procedures.
3. Develop recommendations for a training program to address all procedural changes.

## 3.2 Accomplishments

The objectives of this research were met through the completion of the research tasks listed in Chapter Four and the findings are detailed in Chapter Five. In this study, 29 state DOT's and two federal organizations were surveyed to determine how they determined density target values and conducted testing of compacted soil. It was determined that no other method used for determining density target values used by other states that offered increased efficiency to current SDDOT methods. From the internal review of SDDOT procedures, it was determined that decreasing the transit time between test sites and field laboratories could provide significant savings in time for the inspectors. Secondly, it was determined that South Dakota conducted significantly more density tests in backfill around pipes than almost any other state. A decrease in this testing frequency would also provide a savings in testing time. Also, a review of alternative testing methods determined that in the coming years new methodologies may be available that will be significantly more efficient than current methods. Additional recommendations were made related to training and operations as presented in Chapter 6.

# CHAPTER 4 TASK DESCRIPTION

## 4.1 Research Plan

The work plan for carrying out the research objectives is detailed below. The plan takes the form following the tasks in the original research proposal and details the methods for performing each of the tasks. The information obtained in the accomplishment of these tasks is discussed in greater detail in Chapter 5.

**Task 1.** Review current SDDOT soil and granular material policies and procedures.

A review of the SDDOT "Materials Manual" and the SDDOT "Standard Specifications For Roads and Bridges" was conducted to develop a further understanding of SDDOT policies and procedures with regard to soil density testing. Two SDDOT engineering interns were interviewed to obtain information of their experience measuring soil density values on two different SDDOT projects. The report from the SDDOT research project 91-05 "Essential Testing and Inspection Levels" was reviewed to evaluate how current soil density testing frequencies were developed. Literature on the Ohio curves was also reviewed to understand the history and development of the curves. Finally, eleven soils from various locations across South Dakota were provided by the SDDOT and tested under this task to determine if the Ohio curves were valid for these soils.

**Task 2.** Meet with the technical panel to review the project scope, work plan, and to receive a list of SDDOT personnel to contact.

After award of the contract the principal investigator met with the technical panel to ensure a clear understanding of the objectives of the research and scope of work exists. The principal investigator and technical panel developed a list of SDDOT personnel to contact, as well as contacts from other organizations. The details of the soil testing program were also established at this meeting.

**Task 3.** Meet with the Material Personnel for all four regions, some Area personnel and the SDDOT Soil Engineer, to gain insight into SDDOT existing procedures and problems.

Based on the list of contacts developed in Task 2, the principal investigator conducted meetings with Material Personnel from the Rapid City, Pierre, Mitchell and Aberdeen Regions and selected SDDOT Area Personnel. The discussions focused on how soil density testing was performed in their area, equipment used, training, amount of time to conduct testing, problems with meeting specified testing frequencies, and suggestions for improvement.

**Task 4.** Survey surrounding State DOT's and federal agencies to assess and document their methods, frequencies, procedures, equipment and training requirements for soil and granular density testing. The product of this survey would indicate what methods are most widely used and give a description of each general type of method. A summary in table form indicating the methods used by each should be included.

In order to establish how organizations outside this State conduct field density testing, other states were surveyed to determine what procedures they use to establish soil density target values and conduct field density testing. An eight question survey was sent to all 50 states and 24 responses were obtained. Meetings were also conducted with representatives from the Minnesota, Iowa, Nebraska, and North Dakota DOT's. Telephone interviews were conducted with Wyoming and Montana DOT's. A table of methods used was developed by state showing which methods each uses.

As part of this survey, organizations using the "Humboldt Stiffness Gauge" were sought out and literature on this device was collected and reviewed. The Minnesota DOT has been experimenting with the device for over two years and meetings were held with their researchers to learn of their experiences.

**Task 5.** Compare SDDOT current policies and procedures against the other surrounding DOT's and federal agencies with regards to quality, timeliness and compaction testing differences.

Based on the results of Tasks 1 to 4, a comparison of SDDOT policies and procedures with that of other states and federal agencies was made. Since only a limited number of methods were used by all states, a state by state comparison was not necessary. Rather, a comparison of the methods used with regards to similarities and differences with regards to quality, timeliness and compaction testing methods.

**Task 6.** Prepare a Technical Memorandum to include recommended modern test methods and procedures that will improve efficiency while maintaining or improving quality and analyze how these changes will impact SDDOT resources.

A technical memorandum was submitted to the SDDOT on August 11, 2000. This document was prepared to establish how the information developed to this point in the research can be exploited to make improvements over current SDDOT methods and procedures. The memorandum summarized the progress of the research to date and developed a series of recommendations. This Technical Memorandum also included relevant information on the "Humboldt Stiffness Gauge" and its potential toward meeting the objectives of this research.

**Task 7.** Meet with the technical panel to review the work completed on the previous tasks.

A meeting was held on August 24, 2000 with the technical panel to review all work completed on the previous tasks. From this meeting agreement between the technical panel and principal investigator was made on how to proceed with the remaining tasks. Additionally, the technical panel suggested areas that may require further investigation prior to proceeding with Tasks 8 – 12.

**Task 8.** Provide recommendations on how to implement these changes.

Based on the suggested changes to procedures outlined in the Technical Memorandum and the discussions in Task 7, a series of recommendations were developed. These recommendations are presented as suggested changes to the materials manual, training programs, or materials to be developed.

**Task 9.** Prepare a draft copy of the changes to the SDDOT Materials Manual.

Once a list of recommended changes was accepted by the technical panel, a draft copy of the recommended changes to the SDDOT Materials Manual was developed. These changes were submitted as an appendix to the final report.

**Task 10.** Review current SDDOT training related to soil and granular material compaction testing and recommend appropriate changes.

During the survey phase of this research information was gathered as to how training in this area is currently being accomplished by the SDDOT, other states and federal agencies. From the survey, different ideas on training by other organizations were identified. Based on this review, recommendations affecting the training program were made.

**Task 11.** Prepare a final report and executive summary of the literature review, research methodology, findings, conclusions, and recommendations.

A final report and executive summary was submitted in May 2001.

**Task 12.** Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

An executive presentation was made to the SDDOT Research Review Board in March, 2001.

# CHAPTER 5 FINDINGS AND CONCLUSIONS

## 5.1 Introduction

The research was conducted as outlined in the task descriptions. The tasks outlined in the original research proposal focuses on seven general areas: a) target values and soil density measurement, b) current SDDOT procedures, c) testing of South Dakota soils, d) survey of other states, e) New technologies, f) Evaluation of Training, and g) conclusions. The results of the research tasks will be presented with respect to their relevance to these general areas.

## 5.2 Target Values and Soil Density Measurement

When an engineering material is tested in the field for compliance with a specification, the field measurement is compared to some standard to determine if the sample passed or failed. If soil density is the property of interest to be measured, then a standard, or target value must be established for the soil being tested. The common methods used for determining those target values are the development of moisture density curves for individual soils and the use of a family of moisture density curves.

Field measurement of soil density is often used as a means of determining if adequate compaction has been achieved. The values obtained from testing are compared to the target values to determine if the soil meets project compaction specifications. The common methods for measuring soil density in the field are the nuclear, sand cone, and rubber balloon methods.

### 5.2.1 Moisture Density Curves Developed For Individual Soils

Most states use soil density for soil compaction testing during pavement construction. This is based on the assumption that soil density is an indicator of compaction quality. The desirable density of a soil is typically established prior to actual construction. Compaction testing by either AASHTO T-99 “The Moisture-Density Relations of Soils Using a 2.5 kg (5.5 lb.) Rammer and a 305 mm (12 in.) Drop”, or T-180 “Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop”, establishes moisture-density relationships for a particular soil. From these tests, the maximum dry density and optimum moisture content are obtained. Based on these tests, the contractor is directed to compact the soil to some percentage of that maximum dry density and to a specified range of moisture contents based on the optimum moisture content. A minority of states specify density as a percentage of AASHTO T-180 compaction effort. When T-180 is specified, it is only required on the layer of soil (base) placed directly below the paved surface.

### 5.2.2 Use of a Family of Moisture Density Curves

During this research states were surveyed to determine how soil density target values were established around the United States. Of the states that responded to the survey, some (DE, ID, MI, NY, OH, SC, SD, and WV) use an alternative method for determining the target density values for soils compacted in the field. These states use a family of curves that have been developed in advance for use in their state. For these states (excluding SD), a database of moisture density curves was developed for the local soils. These moisture density curves were plotted together on a single sheet, yielding a family of moisture density curves. This system assumes that any soil encountered in the state is represented by one of those curves. In the field, the technician must establish which curve represents the soil being tested. To do this, the technician runs a one-point Proctor test, where a single specimen is obtained and compacted using AASHTO T-99 procedures. Once the dry unit weight and moisture of that sample is obtained, the data are plotted on the family of curves and the curve that falls closest to that data point is selected to represent that soil. The maximum dry density and optimum moisture content for that curve is then used to be the target value for that soil. South Dakota does not have its own family of curves, but has adopted the Ohio family of curves for use in SD. Idaho has curves developed by region within that state. A telephone interview with the Ohio DOT Construction, Soil and Drainage engineer was conducted during this research to learn how the Ohio DOT uses the Ohio curves. Ohio uses the curves for finer grained soils, but does not use it for coarse soils and therefore considers Ohio curves A through E invalid in their state.

### 5.2.3 Comparison of the Two Systems

Once the target values are established, any field density test may then be compared to the target value to determine compliance with construction specifications. The development of individual moisture density curves for each soil provides a high level of confidence in the target values being used as long as the material being compacted does not change. However, if the compacted soil changes over the construction zone, new moisture density curves must be developed in the field or at a nearby laboratory to represent the new material. This type of procedure typically requires soil samples to be transported quickly to a lab for testing and a rapid relay of results back to the field. This type of system may require a higher level of staffing in the labs along with a reliable transportation system to deliver soil samples to the labs. The advantage of this process is that it provides a high level of confidence in the target value. Secondly, it eliminates the burden of the technician from running a significant number of time consuming one-point tests in the field.

The family of curves approach eliminates the need for conducting the four or five point Proctor test, although these tests may be run to determine if the family of curves is valid for that soil. This tends to decrease the workload on the soils laboratories and eliminates the transportation of the soil samples to the central or regional lab. Additionally, conducting one-point proctors may be more efficient when soil conditions change frequently during the project. However, this methodology assumes that the family of curves being used is valid for the soils being tested. Also, the field inspector must now devote a significant amount of time conducting one-point proctor tests, which may interfere with other duties.

### 5.2.4 Soil Density Measurement

The three methods most widely used for measuring soil density in the field are the nuclear gauge, sand cone, and rubber balloon methods. Based on responses from a large number of states, the nuclear gauge is the most widely used. The nuclear gauge offers the advantage of being able to measure soil density and moisture content at the same time. However, there continues to be concern within South Dakota over the calibration, operation, and accuracy of the device. The sand cone and rubber balloon tests are relatively simple and users feel comfortable with both the equipment and results. Both tests require use of a scale and both of these methods require that the moisture content be determined by a separate test. Because the rubber balloon measures volume directly, it is faster than the sand cone test.

Because the nuclear gauge eliminates the need for a separate moisture test, it can be performed much faster than the other methods. This advantage is even more pronounced if a large number of tests are to be run. Additionally, the nuclear density gauge does not require a scale for weighing soil samples and a separate set of equipment for the determination of moisture content. The disadvantage of the nuclear gauges are the annual costs of licensing, training, field calibration and radiation monitoring. Based on data supplied from the SDDOT, the cost for the state is estimated at approximately $800 per gauge, or about $19,000 per year for the 24 gauges currently operated by the state. Typically, these gauges are replaced every 10 to 12 years at a cost of approximately $6,000.

### 5.3 Testing Methods Used in South Dakota

The South Dakota Department of Transportation (SDDOT) presently uses the Ohio Typical Moisture Density Curves to establish target moisture density values. Field use of one-point results for a comparison to the Ohio Curves can be a time-consuming process. With limited resources, the time spent by SDDOT field personnel on compaction testing reduces time available for other necessary inspection duties.

This process of soil density inspection has created problems for both the inspectors and contractors. For the inspectors, too much time must be devoted to density testing at the expense of other duties, and for the contractor, significant rework may be required due to the delay in obtaining test results.

For the inspector, the frequency of in-place density testing is detailed on the Density Report form (DOT-41). A copy of this form is included in Appendix D. Testing frequency is specified for embankments, berms, pipe backfill, subbase and base course. During interviews with SDDOT employees who performed density testing on the Highway 14 reconstruction in Volga, SD and the Minnesota Avenue/Benson Road construction in Sioux Falls, SD during the summer of 1999, the time required to perform one density test could be up to one hour if that person was working alone. This long testing period may make it difficult for the inspector to perform density tests at the required frequency as specified on the DOT-41. This time-consuming process kept the inspectors away from their projects for an extended period of time while they were working in the lab shack.

The current process used by SDDOT requires a one-point Proctor test be performed nearly every time a soil density test is conducted within a zone. Once the Proctor sample has been compacted, it is weighed, extruded, and a sample is obtained for moisture content testing. Moisture content testing is performed using the stove top method. This method consists of "cooking" the soil on an open stove top at high temperatures to drive off the moisture. Once the sample has been dried to a constant mass, the sample may be cooled and subsequently weighted to determine moisture content.  This method is not recognized by any AASHTO or ASTM specification and can give poor results, especially in clays (FHWA, 1990).  Because this test can not be conducted to any recognized specification, it is subject to numerous errors and the results would be extremely difficult to defend in court should the results be part of any litigation. Currently only four methods of obtaining moisture content are recognized by ASTM:  Oven-dried, nuclear, gas carbide meter, and microwave oven.  AASHTO currently does not have a specification for the determination of the water content of soils by the microwave method.

From the moisture content and the moist density from the one-point Proctor, a dry density is determined.  The moist density and moisture percentage are plotted on the appropriate Ohio Curve and the target value for that test is established.  Each curve has a letter designation and the Ohio Curve table shows the maximum dry density and optimum moisture content for each curve.

An in-place density test is also performed on the compacted soil from which the one-point sample was also taken.  Typically this is done using the sand cone, nuclear or rubber balloon methods.  The sand cone method indirectly determines in place density by filling a hole in the compacted soil with sand of a known unit weight.  The weight of soil used to fill the hole is determined, and that weight is divided by the density of the dry sand.  The result is the volume of the hole.  This method requires use of a calibrated sand cone and should only be used on a site that is not subjected to any vibration (typically from equipment) in the vicinity while the test is being run.  In the rubber balloon method, the testing equipment is placed over a hole dug on site. Pressurized water flows from the device into a membrane which fills the hole and the amount of water contained in the membrane is recorded   The results of the field density test are compared to the values determined from the one-point Proctor/Ohio curve result to determine specification compliance.

For the contractor, if placed materials do not meet specifications, significant quantities of material could be placed by the contractor before final test results were available.  If the placed material failed to meet specifications, a substantial amount of rework by the contractor could be incurred.  This results in construction delays, increased contractor cost and the potential for conflict among all parties.

### 5.3.1 Survey of South Dakota

A number of meetings were held with SDDOT engineers and technicians to discuss soil density testing within the state. Most engineers expressed the opinion that they were satisfied that soils were being compacted properly and that there was a low rate of failure as a result of soil testing. In general, the SDDOT has an extensive amount of road construction taking place in the state, and the number of required tests for the personnel assigned do not allow for adequate supervision of contractor work.

The methods of testing the in place density of soils has not changed significantly in recent years. However, from discussions with SDDOT personnel it was evident that reductions in staffing has made it increasingly difficult to meet the minimum required test frequency. The primary purpose of the interviews was to review SDDOT procedures and develop an understanding of the tasks that were the most time consuming.

Current procedures call for the optimum moisture and maximum density values (4-point method) be determined for materials prior to, or at the time of field compactions are measured. The 4-point determination is performed to verify if the family of curves is valid for that material. From the test data a moisture-density curve is plotted and the optimum moisture and maximum density are determined. From the 4-point curve a point is selected 1 ½ to 2 % below and on the dry side of optimum moisture. The corresponding point on the accompanying 4-point wet curve is used to select and identify, from the wet curves of the proposed family, the curve to be used for the standard (target). The maximum dry density from this curve must be within ±4 pcf (for soil) or ±3 pcf (granular) of the 4-point maximum dry density for the family to be valid.

In the field, soil density tests are taken at or above the frequency specified on the DOT-41 form. When a field density test is performed, a 1-point determination using material from or adjacent to the hole is performed for each in-place test. This test is performed to establish the target value from the family of curves. The results of the field density test are then compared to the maximum density value obtained from the family of curves to determine acceptance.

One of the greatest concerns was that the inspectors are spending little time observing the contractor work. The procedures and equipment used by the SDDOT tend to keep the inspector off the job site, which allows the contractor to work unsupervised. It was recognized by some of the DOT personnel interviewed that in many cases, observing the contractor work and keeping field notes tended to cause the contractor to pay more attention to the job. This supports comments from other states who stated that an inspector should always be on site and observing the work.  In South Dakota, the requirement for frequent one-point tests requires that the inspector spend a significant portion of their day either in the field lab or in transit between the field lab and the job site.  In many cases, the inspector is on the site long enough to collect a sample, and then drive to the field lab to conduct testing.

A second area of concern was the required frequency testing for pipe backfill.  As will be presented in the results of the survey of other states, South Dakota requires more testing in pipe backfill soils than any of the states that responded to the survey.  In addition to the high frequency of testing, a one-point determination must be done for nearly every in-place density test.  It was estimated that a single in place density test, accompanied by a one-point determination would take an experienced inspector approximately 30 minutes.  These times could easily increase if the field lab was not located near the inspection site.

A third concern was the use of nuclear density gauges for soil density testing.  The amount of testing by nuclear gauges varied from region to region in the state.  In some regions the gauges were primarily used for asphalt and bridge deck testing.  Some regions used their gauges for soil density testing, but did not have confidence in their results, especially for moisture content.  Use of the nuclear gauge does not significantly speed testing times because one- point determinations are still required.  However, it does allow for more frequent testing of soil density above the minimum required by the state Materials Manual.

A final concern arises when a curve (either by a four-point test or family of curves) has been determined for the soil, and the soil source, appearance, moisture content and construction methods are unchanged, additional one-points are required to validate that the selected curve is still valid.  In this case an experienced inspector, who has spent considerable time on the project must verify the target values even though there has been no observed change in either the materials or methods.  If the material is unchanged and it continues to meet the required density and moisture specifications, it may not be necessary to perform the additional one-point.  If the material test fails, then the one-point may be done to determine if the soil has changed or if the contractor needs to rework the soil

In general, the procedures specified in the Materials Manual appear to be developed with the least experienced employee in mind.  The restrictive and sometimes burdensome requirements do not allow the state to take advantage of the experienced and highly qualified field technicians, nor does it allow the regional material engineers the ability to exercise judgement based on staffing, experience and work loads.

### 5.4 Testing of South Dakota Soils

South Dakota uses the Ohio family of curves to establish target values for soil density testing. This is somewhat unique as most states that use this approach have developed their own curves based on the results of tests from soils within their state. One of the tasks of this research project was to test some typical South Dakota soils to determine if the Ohio curves would be valid for those soils. The SDDOT provided eleven soil samples to be tested. For each soil sample a gradation test and moisture density test (T-99) was performed. From this data the soil classification of the soil could be established as well as the optimum moisture content and maximum dry density for the T-99 compaction effort. After testing was completed, a comparison was made between the test data and the Ohio curves.

To determine if the Ohio curves applied to these soils, data points from the lab tests were plotted on the Ohio curve to determine which Ohio curve would apply to that soil. The maximum dry density and OMC for that curve were recorded and compared to the actual maximum dry density and OMC for that soil.

#### 5.4.1 Soils Tested and Results

Eleven soils were submitted for testing. The soils tested were obtained from various locations as listed in Table 1.

Most of the soils tested had less than 2% passing the number 200 sieve, and all samples had less than 5% pass the number 200 sieve. The grain size distribution of each soil was determined per AASHTO T-27-93 “Sieve Analysis of Fine and Coarse Aggregates”. The samples were mixed and equally split for moisture-density testing. Moisture density tests were conducted per AASHTO T-99 “The Moisture-Density Relations of Soils Using a 2.5 kg (5.5 lb.) Rammer and a 305 mm (12 in.) Drop”. Four or five data points were run for each soil sample depending on the mass of soil in the original sample

| Soil Number | Submitted By | Description | Classification (USCS) |
|---|---|---|---|
| 1 | Aberdeen Region | Brookings County, NW ¼, NW ¼, SW ¼, Sec 13, 110 Twp., 51 Range | SP |

| | | | |
|---|---|---|---|
| 2 | Aberdeen Region | Day County, Sec. 9, 125 Twp., 55 Range | SP |
| 3 | Aberdeen Region | Brown County, SW ¼, Sec. 27, 127 twp., 64 Range | SP |
| 4 | Pierre Central Office | | SW |
| 5 | Aberdeen Region | Brown County, SW ¼, Sec. 27, 127 twp., 64 Range | SP |
| 6 | Mitchell Region | Pete Brenden Pit, Davison County, Track 3 of Lot 3, NE ¼, Sec. 27, T103N60W | SP |
| 7 | Mitchell Region | Sanborn and Minor County, SD Hwy 34 Project | SW |
| 8 | Mitchell Region | Davison County, Sec. 23, T104N-R60W | SP |
| 9 | Aberdeen Region | Brookings County, NW ¼, NW ¼, SW ¼, Sec. 13, 110 Twp., 51 Range | SP |
| 10 | Aberdeen Region | Brookings County, Lot A, SE ¼, Sec. 16, 110 Twp., 51 Range | SP |
| 11 | Mitchell Region | Borrow from near Shindler, SD, Sec. 21, T100N, R49 W, Lincoln County | SW |

Table 1 Number and Location of Soil Samples

**Comparison of Lab Data to Ohio Curves**. The SDDOT Materials manual states that moisture density tests conducted in the field must be done at a moisture content that is within the range of –2 to +1 % of the OMC. For each moisture-density test conducted in the laboratory, the unit weight at –3, -2, -1, and +1 % of OMC was recorded. For example, from the test one moisture-density curve the wet density at –2 % was determined. These data were then entered into the Ohio curve to determine which Ohio curve would have been selected for those data. This was to treat that data point like it was a result obtained from a one point test conducted in the field, and to determine the OMC and maximum density from the Ohio curves that would have been obtained from that data. The OMC and maximum density from the Ohio curve was then compared to the actual OMC and maximum density from the lab test. These results are shown for all tests in Table 7 located in Appendix C.

Table 8 (Appendix C) lists the maximum density from the lab test and the maximum density that would have been selected for the Ohio curve that corresponded with that one data point. Table 9 (Appendix C) was developed in a manner similar to Table 3, except that it shows the difference between the actual OMC and the OMC from the Ohio curve that would have been selected for each data point.

From the results shown in Tables 8 and 9, tests 5 and 7 have significant variations from the Ohio curves. Additionally, sample 6 did not provide a clear moisture-density relationship. Due to the limited amount of soil available, additional tests could not be performed to obtain a definable moisture-density relationship.

When analyzing the data from these tests, it can be seen that the difference between the maximum density from the lab tests and the maximum densities from the Ohio curves was three pounds per cubic foot (wet density). The difference in the OMC's was 1.7 %. If tests 5 and 9 are not included in the data set, the average differences in maximum wet densities drops to 1.8 pcf and for OMC the average difference drops to 1.2%.

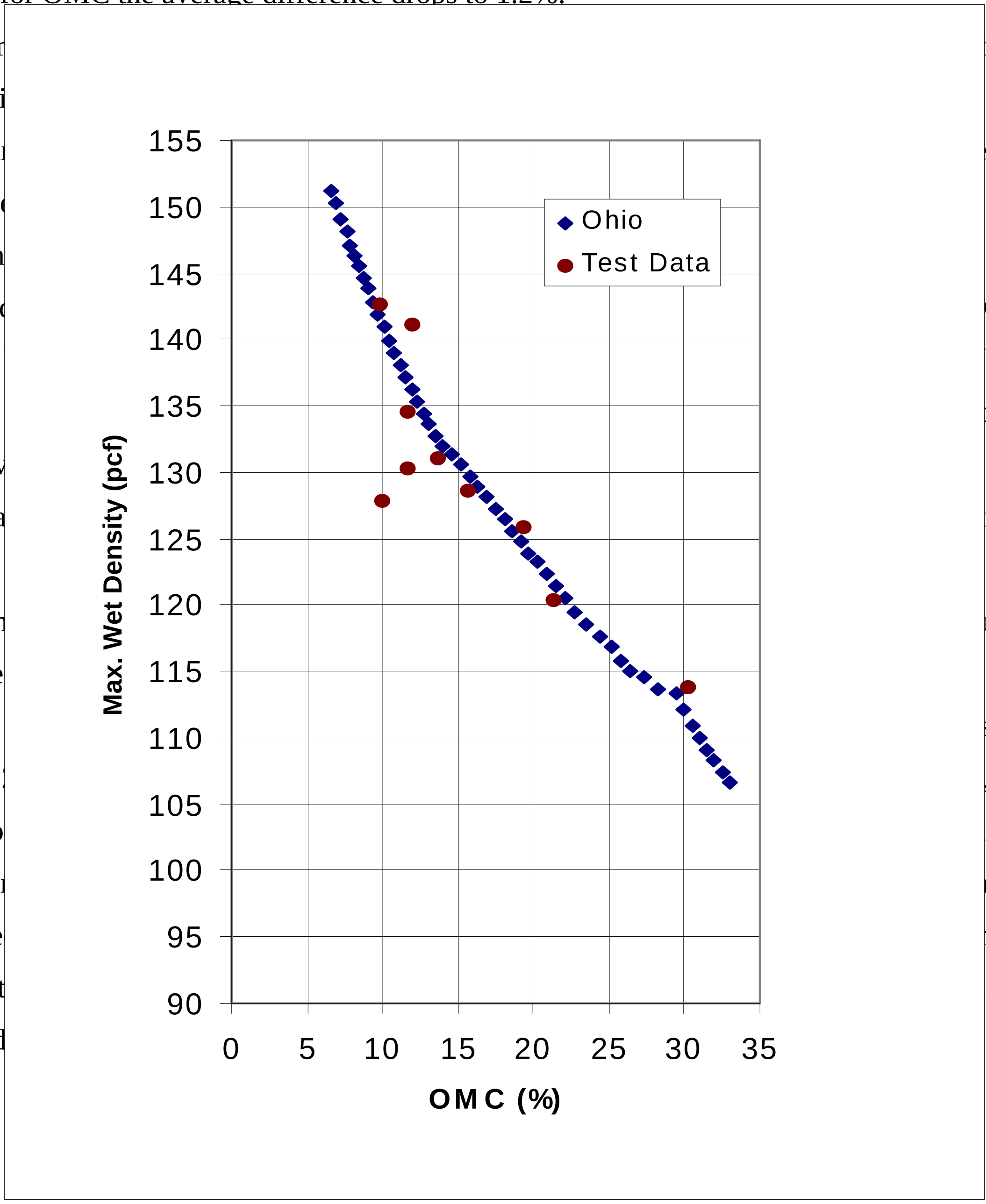


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**Figure 1 Comparison of Ohio Curves to Research Test Results**

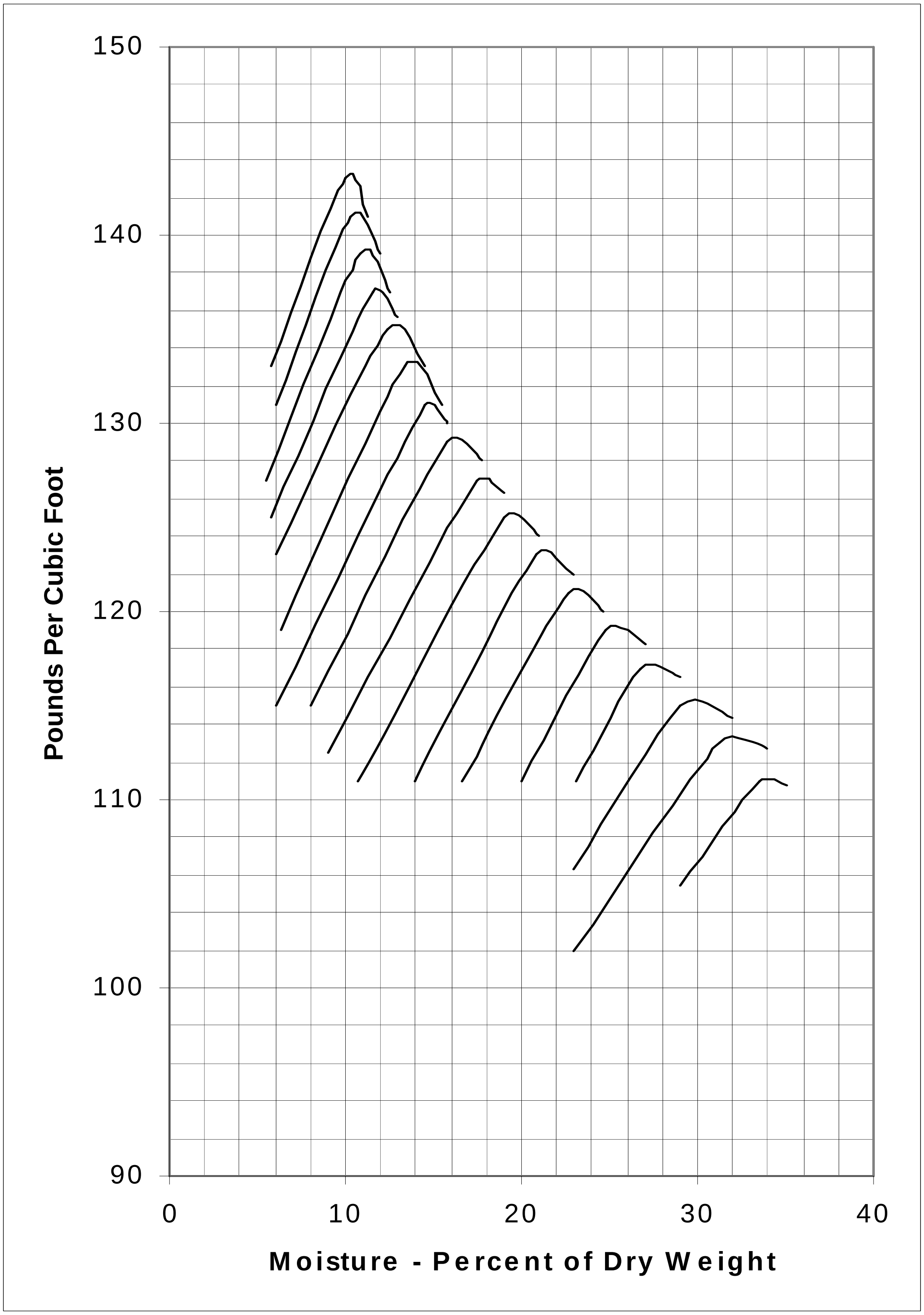


**Figure 2 Example of Family of Curves Based on Research Test Data**

### 5.5 Survey of Other States

In an effort to seek out alternative, and perhaps improved methods for the inspection of compacted soils, other states were contacted to determine what other methods may currently be in use. It was envisioned that the information with other states might lead to improved and more efficient testing methods.

In the original request for proposal, one of the stated tasks was to "survey surrounding states and federal agencies to assess and document their methods, frequencies, procedures, equipment and training requirements for soil and granular density testing". In an effort to gain additional information on this task, it was attacked in two ways. First, a short survey was sent via email to materials or geotechnical personnel from each of the DOT's that did not share a common border with South Dakota. In the survey a brief discussion on the project was presented, followed by eight questions. The survey was intended to be brief, in hopes that the recipient would be more likely to answer a short survey than a lengthy one. The survey questions were as follows:

1. How do you establish the compaction properties of the soils used in a project, and how often must they be validated? (i.e. four-point proctor, gradation, etc.)
2. How do you test soil density in the field (sand cone, nuclear, rubber balloon, penetrometer, etc.)?
3. How do you test soil moisture in the field (nuclear, microwave, stove-top, etc.)?
4. What is your required frequency of field testing for embankments, base course, culvert backfill, subbase and is it based on volume of material placed or spacing?
5. How are your personnel trained (formal class, on the job, etc.)?
6. Are visual inspections allowed?
7. How long does it take from the start of the test until the contractor is informed that the sample has passed or not?
8. Please add any other comments that might be helpful.

For the states surrounding South Dakota, personal visits were made with representatives from the North Dakota, Minnesota, Iowa, and Nebraska DOT's. Telephone interviews were conducted with representatives from the Wyoming and Montana DOT's.

#### 5.5.1 Survey Results

Of the 50 states, seven were contacted personally and 43 by email. Of the states surveyed by email, nine had addresses that were not deliverable, 12 chose not to respond, and 22 responded.

Therefore 29 of the states, or 58 %, were contacted as part of this project. The Federal Highway Administration and US Army Corps of Engineers were also surveyed.

The responses from the states varied. Some states responded by mailing boxes of information including specification books, training manuals, videos, CD Roms, materials manuals, as well as other information. Some states also provided information on their web sites, some of which had their entire training programs and standards available via the web. Other states simply responded via email. The nature and extent of the response suggests that the data collected is a representative sampling of soil density testing procedures in the United States.

The following tables show a brief summary of the survey results. The requirements listed by each state are their minimum test requirements. The measurement of frequency will vary because states use a different basis for how often to test. It may be based on a unit volume, unit weight, unit distance, or per lift basis. Additionally, most states rely on nuclear gauge testing, which may allow for increased testing frequency. Some states allow the inspector to determine testing frequency by observation or simply use proof rolling. Table 2 lists survey results for embankment testing, Table 3 for base course testing, Table 4 for pipe backfill and Table 5 lists the preferred testing equipment used by each state as well as the length of time to provide test results to contractors.

**Target Values**. Of the states that were contacted, eight of the 29 (28%) use a family of curves and conduct one point proctors in the field. With the exception of South Dakota, all states use a family of curves developed for their own state. North Dakota also has a family of curves, but prefers to perform a T-99 compaction test for each soil. Minnesota does not routinely use field density testing for soil testing, however if it does, it develops a unique moisture density curve for each soil encountered on a project. Iowa currently does not routinely use a density specification, although it may be called out on occasion. Iowa typically uses a roller walk out specification or requires the contractor to make a specified number of passes per lift with a specified equipment type. Iowa is in the process of changing this specification to either a density based or penetration based specification. The remaining states (66%) develop moisture density curves for each soil encountered on a project. From the survey it was determined that 93 % of the states are using a density based specification for soil testing. Of the two that are not using density testing exclusively (IA and MN), they do allow its use.

| State | Density Target | Density | Moisture | Remarks |
|---|---|---|---|---|
| AK | Mod Proctor | 1/10,000 T | | Proctor tested @ central lab |
| CO | Proctor each material | | | |
| CT | Modified Proctor | 1/5000 cy | 1/5000 cy | |
| DE | Delaware Curves | 1/1,000 cy | 1/1,000 cy | |
| FL | 1 Std Proctor ea. mat'l type | 1/500' on Alt. 6" lifts<br>1/500' on every 12" lift | | 102% Std. Proctor if $\gamma$ = 100-105 pcf<br>100% Std. Proc. if $\gamma$ >105 pcf |
| ID | Regional Idaho Curves | 1/2500 cy, no less than 1 per lift | | |
| IA | Roller walk out -<br>Lifts/compaction eq./ & # passes specified | | | |
| KS | 1 std Proctor ea mat'l type | 4 day in top 18", all others visual | 4 day in top 18", visual | |
| KY | Proctor ea. mat'l type | 1 per 2' el. per 1000 lf | | |
| MD | Proctor ea. mat'l type | 1 per 2,000 cy min. | | |
| MI | MI Curves | 1 per 1,000 cy | | |
| MN | 1 Proctor ea mat'l type | Upper 3' – 1/2500 $m^3$ (LV)<br>Below 3' – 1/3500 $m^3$ (LV) | | |
| MO | 1 Proctor ea mat'l type | Not Specified | | |
| MT | Proctor ea mat'l type | A-1 to A-3 1 per 4,000 cy<br>A-4 to A-7 1 per 2,000 cy | | |
| ND | Proctor ea mat'l type or ND curves | 1 per ft. lift per 1500 ft of roadway | | |
| NE | Proctor ea. mat'l type | 1 per 1-3,000 cy | | |
| NJ | Std Proc. ea mat'l type | Control Strip | | |
| NY | New York Curves | 1/day/fill or 1/10,000 cy | | |
| OH | OH Curves – fine grained | "uniform Conditions" | | Engineers Judgement/ Proof rolling |
| RI | Std Proc. Ea Matl type | 1 per 100 to 3000 cy yd | | |
| SC | SC Curves | 1 per 4000 cy | | |
| SD | Ohio Curves | 1 per half mile | | One per zone |
| TN | 1 std proctor ea mat'l type | 1/lift/1500 LF or 5000 cy | 1/lift/1500 LF or 5000 cy | |
| VA | One pt proctor | 1/8,000 $m^3$, 1 test every other lift | | |
| VT | | 1 per 3,000 cy | | |
| WV | WV Curves – 1 pt. Per lot | 1 per sublot (<2500 cy) | As required | 1 lot = 5 sublots |
| WY | Proctor ea. Mat'l type | A-1 to A-3 1 per 4,000 cy<br>A-4 to A-7 1 per 2,000 cy | | |
| COE | Proctor ea. Mat'l type | | | |
| FHWA | Proctor ea. Mat'l type | 1/4000 $m^2$ or 1/layer | | |

**Table 2 Survey Results from Embankment Testing**

| State | Density Target | Density | Moisture | Remarks |
|---|---|---|---|---|
| AK | Mod Proctor | 1/2000 T | 1/2000 T | |
| CT | Modified Proctor | 1/3000 T | 1/3000 T | |
| DE | Delaware Curves | 1/1,000 CY | 1/1,000 CY | |
| FL | Mod. Proctor – 1/lift/road mile/source | 1/lift/500 ft for subgrade/base | | Gradation – 1/Lift/road mile/source |
| ID | Idaho Curves | 1/900 tons | 1/900 t | |
| IA | Roller walk out - Lifts/compaction eq./ & # passes specified | | | |
| KS | 1 std proctor/mat'l type | 1/1000 ft | 1/1,000 ft. | |
| KY | 1 Proc. /ea. mat'l type | 1 per 500 sy | | |
| MD | Proctor ea. mat'l type | 1/day or 2 per 2 lane mi | | |
| MI | MI Curves | 1 per 500' per width of 24' or less | | |
| MN | 1 Proctor/ea mat'l type | 1 per 1,000 cy | | |
| MO | 1 Proctor ea mat'l type | Not Specified | Not Specified | |
| MT | Proctor ea. mat'l type | A-1 to A-3 1 per 4,000 cy<br>A-4 to A-7 1 per 2,000 cy | | |
| ND | Proctor ea mat'l type | 1 per ft. lift per 1500 ft | | |
| NE | Proctor ea. mat'l type | 1 per 1000'/ft lift | Not Specified | 100% T 99 |
| NJ | Mod Proc per mat'l | 5/800 $m^3$ or 5/4,000 $m^2$ | 5/800 $m^3$ or 5/4,000 $m^2$ | |
| NY | New York Curve | 1 day or 1 per 10,000 cy | | |
| OH | Granular – Proctor/source | 1/1,000-3,000 cy | Not Specified | 1 pt. Proctor w/ea. density |
| RI | Std Proc. Ea. Matl type | 1/ 300 to 3000 cy | | |
| SC | SC Curves | 1/1000' per layer | | |
| SD | Ohio Curves | 1/mile per lift | | per roadbed |
| TN | Std Proctor ea. mat'l type | 1/10,000 sy | 1/10,000 sy | |
| VA | One pt Proctor | | | |
| VT | | 1/5,000 cy | | |
| WV | WV Curves | 5 da. Or 500'<br>5 per 75 ft.<br>1 per lift ea. 75 ft. | | Water & Sewer<br>Culverts < 60" dia<br>Culverts > 60" dia |
| WY | Proctor ea. Mat't type | A-1 to A-3 1 per 4,000 cy<br>A-4 to A-7 1 per 2,000 cy | | |
| COE | Proctor ea. Mat't type | | | |
| FHWA | Proctor ea. Mat't type | 1/500 Tons | | T180 |

**Table 3 Survey Results for Base Course Testing**

| State | Density Target | Density | Moisture | Remarks |
|---|---|---|---|---|
| AK | Mod Proctor @ central lab | 1 per pipe/As required | | |
| CT | | Not Specified | | |
| DE | Delaware Curves | >1/1,000 CY | | |
| FL | 1 proctor/type of mat'l | 1/500' on Alt. 6" lifts<br>1/500' on every 12" lift | | |
| ID | Idaho Curves | 1/100 LF | | |
| IA | | Not Specified | | |
| KS | 1 std proctor/mat'l type | Visual | | |
| KY | 1 std proctor/mat'l type | 1 per 2' elev per 1000 lf | | |
| MD | Proctor ea. mat'l type | 1 per 3 ft. depth per 150' | | Pipe trench |
| MI | Michigan Curves | 1 per 400 ft | | |
| MN | 1 std proctor/mat'l type | Not specified | | |
| MO | 1 std proctor/mat'l type | Not specified | Not specified | |
| MT | Proctor ea mat'l type | Inspectors Judgement | | Min. 1 per site |
| NE | | Inspectors Judgement | | |
| NJ | Std proctor | 5 per 765 $m^3$ or 1 m elev | | |
| NY | New York Curve | 1/day /culvert or 1/500 cy | | |
| OH | Ohio Curves | 1-3,000 cy | | |
| RI | Std Proctor Ea. Matl type | 1/ 300 to 3000 cy | | |
| SC | SC curves | | | |
| SD | Ohio Curves | 1 per 1/3 & above & below | | For >72" pipe, less for smaller pipe |
| TN | | "shall be thoroughly compacted | | |
| VT | | | | |
| VA | 1 pt. Proctor | 1 test per lift, on alt. sides | | |
| WY | | Not specified | | |
| FHWA | | Not Specified | | |

**Table 4 Survey Results for Pipe Backfill Testing**

| State | Density | Moisture | Timeliness |
|---|---|---|---|
| AK | Nuclear | Nuclear | 10-15 minutes |
| AZ | Nuclear | Nuclear | No Response |
| CA | Nuclear | Nuclear | No Response |
| CO | Nuclear | Nuclear | Varies |
| CT | Nuclear | Nuclear | Promptly |
| DE | Nuclear | Nuclear | Approx. 30 minutes |
| FL | Nuclear | Nuclear or Speedy | 1 – 2 weeks |
| HI | Nuclear | Nuclear | No Response |
| ID | Nuclear | Nuclear | Varies |
| IA | Nuclear | Nuclear | Varies |
| KS | Nuclear | Speedy or oven | Within one day |
| KY | Nuclear | Speedy | Immediately or within 1 hour |
| MD | Nuclear | Stove top | Immediately |
| MI | Nuclear | Nuclear | Approx. 15 minutes |
| MN | DCP, Sand Cone | Stove top | Approx. 15 minutes |
| MO | Nuclear | Nuclear | Varies significantly |
| MT | Nuclear | Nuclear | Varies |
| NE | Nuclear | Nuclear | Varies |
| NJ | Nuclear | Nuclear | 1-4 hours |
| NY | Nuclear/sand cone | Nuclear, Stove top | Varies |
| ND | Sand Cone | Speedy, Stove top | Varies |
| NV | Nuclear | Nuclear | No Response |
| OH | Nuclear (90%) | Nuclear, Speedy | 30 minutes |
| OR | Nuclear | Nuclear | No Response |
| RI | Nuclear | | 18 to 30 hours |
| SC | Nuclear | Nuclear | Minutes if one point not req'd |
| SD | Sand Cone, Balloon, Nuclear | Stove top | 30 to 60 minutes |
| TN | Nuclear | Nuclear | A short time period |
| UT | Nuclear | Nuclear | Varies |
| VA | Nuclear | Nuclear | After the test is complete |
| WA | Nuclear | Nuclear | No Response |
| WV | Nuclear | Nuclear | Immediate |
| WY | Sand Cone | Stove top/micro | Varies |

**Table 5 Survey Results for Instruments Used**

Minnesota is the only state that currently uses strength testing techniques for testing soil compaction in the field, although others are experimenting with these technologies. They currently use the dynamic cone penetrometer for this type of testing and have been conducting extensive trials on deflection based testing methods. These methods are discussed in the following section titled “New Technologies”.

**Test Frequencies**. Comparing the testing frequencies from state to state can be difficult because of the differences in the basis of measurement. The testing frequencies for South Dakota were investigated in research project SD 91-05 “Essential Testing and Inspection Levels”. With regard to the frequency of density testing for embankments and base course, no changes were made as a result of that project. For embankments the report stated that even though South Dakota had a relatively low testing frequency, the rate of failure was relatively low. Since that report was completed, the states neighboring South Dakota have maintained the same test frequency requirements for embankments and base. The only change was in Minnesota where the test frequency for base course was changed from 1 test per 500 CY to 1 test per 1,000 CY.

The one inspection item that was not discussed in the 91-05 report was the frequency of pipe backfill testing. Table 4 lists the data received from the states that responded to the survey with regards to pipe backfill testing. Because many states specify their frequency in a different manner, it was necessary to convert them to a common base. To accomplish this, an estimate of the minimum number of tests required by each state was made for a 260 foot section. Two sets of test frequencies were established, one for a 24 inch pipe and one for a 72 inch pipe. It was assumed the 24 inch pipe came in 6 foot long sections and was installed in a trench that was 4 feet wide and 4 feet deep. For the 72 inch pipe, it was assumed the pipe came in 4 foot long sections and that the trench was 12 feet wide and 8 feet deep. The depth of burial is based upon the SD testing requirement that pipe backfill must be tested 2 feet above the pipe. After that depth other testing criteria applied.

As shown in Table 6, South Dakota specifies more density testing around pipes than almost every state that responded to this survey. Of the 25 states that responded to this part of the survey, eight have no specific frequency, five allow “inspectors judgement”, while the others detail a specific frequency. With regards to the 24 and 72 inch pipe, only three states specify a frequency that is close to South Dakota.

| State | 24 Inch Pipe | 72 Inch Pipe |
|---|---|---|
| AK | 1/100 ft. | 1/100 ft. |
| DE (1/1000 CY) | 1/1688 ft. | 1/281 ft. |
| ID | 1/100 ft | 1/100 ft |
| FL | 1/100 ft | 1/56 ft. |
| KY | 1/500 ft. | 1/250 ft. |
| MD | 1/75 ft. | 1/50 ft. |
| MI | 1/338 ft. | 1/400 ft. |
| NJ | 1/338 ft. | 1/56 ft. |
| NY | 1/844 ft. | 1/141 ft. |
| OH | 1/5063 ft. | 1/844 ft. |
| RI | 1/500 – 1/5000 ft. | 1/84 – 1/844 ft. |
| SD | 1/87 ft. | 1/52 ft. |

**Table 6 Pipe Test Frequency of Other States on a Per Foot Basis**

None of the personnel interviewed in the SDDOT were aware of how the testing frequency for pipe backfill was developed. However, all who were interviewed mentioned how difficult it was, especially in urban areas, to achieve the required testing frequency without slowing construction. This was also mentioned as one of the tasks that could keep inspectors from performing other inspections because of the time and attention necessary to meet the required test frequency. The only response that gave a hint as to how this was developed was that there had been problems with differential settlements in some pipes, and that this test frequency was developed to possibly address this problem. Without determining the cause of the pipes settling, it is impossible to tell if increasing backfill test frequency is an appropriate response.

From a soil mechanics standpoint, differential settlement is caused by non-uniform conditions in the material upon which the engineered structure (in this case the pipe) rests. The properties of the soil adjacent to the pipe should not have a significant affect on that problem. The placement of the backfill soil would control how much the surface of trench settled after backfilling. To address pipe settlement, the soil upon which the pipe is to rest should be adequately prepared and have uniform properties over the length of the project.

To address this problem, the state should consider how the soil under the pipe is prepared, and then consider reducing the test frequency of the backfill soil.

**Equipment Used**. With respect to the type of equipment used to measure soil properties in the field, information from 33 states was obtained. Of these, 29 of the 33 (88%) use nuclear gauges for soil density testing. This includes Iowa, which uses nuclear gauges when it performs density testing. North and South Dakota, Wyoming and Minnesota use sand cones, however Minnesota also uses the dynamic cone penetrometer. In interviews with some of the states that test with nuclear gauges, the speed of testing was reported as the primary reason for its use. Most states appear to have resigned themselves to the regulatory requirements and overhead costs associated with the nuclear gauges because it allows them to do more testing in less time.

**Timeliness.** Each state was asked how long it took for field density test results to be reported back to the contractor. Many states did not report a specific time as they felt it varied significantly from job to job. The 17 states that did provide specific times stated that the times were approximate. Ten states said the density results are reported immediately or within about 15 minutes. These were typically from states using nuclear density gauges and not performing one-point determinations. Three states reported it took 30 to 45 minutes to provide results, and the remaining four states reported it took hours and even days to provide results. In conversation with some of the personnel interviewed from outside the state, they felt no obligation to provide instantaneous results to the contractor. The contractors were typically well aware of the time required to obtain test results, and therefore should plan their work accordingly.

## 5.6 New Technologies

The primary objective of compaction is to increase soil stability and improve the engineering properties of the soil. Although dry density and water content have been used for years as a measurement of compaction quality, they are not the primary objective of compaction. The strength of the soil as well as its ability to resist deformation under load are often the primary objective of compaction. These engineering properties are often reflected by the density of the soil, but there is no unique relationship between moisture density measurements and soil strength or deformation properties.

In an effort to determine the deformation characteristics of soil under load, new testing devices are being developed that provide quantitative measurements of soil stiffness. These gauges include the Humboldt GeoGauge™, Loadman portable falling weight deflectometer (FWD), Prima 100 hand held FWD, and other devices. These devices are all designed to measure the deflection of soil subjected to a specified load.

Within the scope of this research effort, an initial investigation into the Humboldt GeoGauge™ was conducted. A review of numerous research reports and manufacturers literature was conducted along with interviews of users of this device.

The Humboldt gauge weights approximately 23 pounds and is operated by a set of D-cell batteries. The device is approximately 11 inches in diameter and 10 inches in height. A metal ring of 4.5 in. outside diameter and 3.5 in. inside diameter protrudes from the base of the device. Prior to testing, the ring is pushed into the soil and is held in place by the weight of the gauge. During testing, the device generates small dynamic forces by means of an internal shaker at frequencies of 100 to 200 Hz. These forces produce small deflections in the soil that is measured by an internal geophone. During operation, the soil is subjected to a series of 25 discrete frequencies of increasing magnitude. The stiffness of the soil to each frequency is measured and the results of the readings are averaged and displayed on the screen on the top of the device.

Lenke, et al. (1999) conducted tests using the Humboldt gauge on silica sand in a cubical test bin. Comparing experimentally determined values with a computational estimate of stiffness showed the error between the two values was less than 5%.

In Texas (Chen, et al., 1999), the Humboldt gauge was employed to measure the in-situ resilient modulus of base and subgrade materials. For comparison, FWD and nuclear density gauge tests were applied to the same site. Over 100 field tests were conducted over 6 Texas Districts. The report concluded that the Humboldt gauge has the potential to be used as a quality control device and that the values obtained were consistent with the FWD. There was some concern as to the ability of the gauge to provide accurate results for stiffer ($>1.6x10^6$ lb/ft) soils. Additionally, the device was determined to be simple and fast, but only yields stiffness values for the top layer of material. Typical measurements were for lift thickness' of six inches. The report also stated that correlation between density and stiffness was very poor.

The Minnesota Department of Transportation (MnDOT) has been experimenting with the Humboldt gauge for over the last three summers. In 1999 (McKane, 2000) a series of tests were conducted at the MnROAD research facility. During this testing a Falling Weight Deflectometer, Humboldt gauge, Portable FWD, and Dynamic Cone Penetrometer (DCP) were used. This report concluded that the portable FWD and the Humboldt gauge gave similar results throughout the study.

As a result of their research program, MnDOT has accepted the DCP for use in soil testing. A specification has been developed which is now part of their standard specifications for construction. At present, Minnesota has not developed a specification for the Humboldt gauge. The device currently measures soil properties for a depth of approximately six inches. The device is viewed as promising because of it's cost, simplicity of operation and speed. However, more investigation is necessary to determine their accuracy in a wide range of soil types and how to correlate results to density.

The cost of the Humboldt gauge is approximately $5,000, and can be used without extensive training. Because the device is relatively new, long term maintenance costs have not been established.

Starting this fall, the FHWA is sponsoring a pooled study among the states to do a more comprehensive evaluation of the Humboldt stiffness gauge. Currently approximately 20 states have chosen to participate in the study and more are expected to participate as the start date approaches. This study would provide a more comprehensive evaluation of the device and its suitability to test soil.

The advantage of converting to a stiffness based, rather then density based specification affects both field testing and the design process. First, using stiffness as the standard for compacted soil acceptance eliminates the need for the development of target values as used in current practice. The elimination of four-point or one-point Proctors would realize a significant labor savings to the DOT. Secondly, the device can complete a test in about two minutes. Humboldt is currently developing methods for their device to measure moisture content as well as stiffness. The portability and speed of testing this device offers would allow for more testing in a shorter period of time. The benefit of frequent testing is that it would ensure the soil had one of the most critical aspects required of a pavement foundation - uniformity.

With respect to design, stiffness measurements of soil would provide the necessary input for mechanistic pavement design. In the coming years the new AASHTO pavement design manual will include a mechanistic pavement design methodology. Under that design process, the stiffness of the individual layers of the pavement would be input variables. Environmental data would also be input to allow the design method to establish the change in stiffness with respect to seasons. Based on this and other input data, layer thickness' would be established. Then, during construction, the stiffness values used in design would then be validated in the field. This process would serve to reduce the empirical nature of pavement design.

**Soil Moisture Testing Devices**. There are many devices used to measure the moisture that are used by those in the agricultural field. To determine moisture content of soils, plant science researchers at SDSU rely on oven-dried and nuclear methods, as do civil engineers. Many other devices exist that are reported to measure moisture contents using electrical resistance, conductance, or other electrode-based devices. Their experience and research show that these devices need significant calibration on actual soils prior to use. These types of devices are very sensitive to the presence of ions in the soil (i.e. salts), and therefore frequent calibration is necessary. Other devices are used to measure moisture and humidity, but provide only estimates and would not meet the accuracy necessary for soil testing. These devices are often used to provide the user with enough information to determine if the soil or product is too wet or too dry.

## 5.7 Training

For many years, training of personnel who conducted soil testing was done by co-workers or supervisors. Currently, the SDDOT has established a formal course for soil testing technicians. One of the primary benefits of this standardized course is that personnel from all offices are given the same training. When training was conducted locally, the potential for variation in the skills of the technicians across the state was much greater. The purpose of a standardized training program is to ensure that soil samples will be tested by consistent procedures throughout the state, no matter which technician performs the test. With respect to the field testing of soils, the state training effort appears to be consistent with the training in other states. In addition, the training program clearly reflects the procedures specified by the SD Materials Manual.

As with any recurring training program, the offices that conduct the training must continue to look for feedback from their students in an effort to make continual improvements to the program.

One area of training that was not as well documented was the training of summer interns. These employees are often not able to receive any comprehensive or formal training. This is due to the fact that they start their employment at different times and therefore cannot be trained as a single group. In addition, they tend to report to work at a time when the full time employees are already in the field performing testing. These employees, who may have no experience with soil testing, are often trained on-site or perhaps briefly back at the lab.

Additionally, SDDOT personnel are not trained on using the microwave oven technique for determining the water content of soils. AASHTO specifies methods for using the gas carbide meter, oven, and nuclear gauge for moisture determinations. ASTM specifies the same methods as AASHTO and additionally provides specifications for the determination of soil moisture content by use of a microwave oven.

**Nuclear Gauge Training**. The procedures on the use of the nuclear gauge for soil density and moisture content testing were obtained from NY, ID, WV, TN, MI, SC and OH DOT's. The documentation from each state was quite similar in their content. Typically, each state had material that outlined radiation characteristics, safety, storage, transportation and emergency procedures associated with the safe handling of the nuclear gauges. The operating procedures were very similar from state-to-state. All states outlined the procedures for a daily standardization of the gauge through the use of a standard reference block. If the standard calibration readings fall outside the specified limits set forth by the manufacturer's manual, then the gauge should not be used. If the gauge does not meet the manufacturer's limits, then each state specifies that the gauge must be recalibrated. In some cases, the recalibration method is not specified. However some states require the recalibration be performed by the manufacturer. Idaho allows for recalibration to be performed by the manufacturer or by other methods as approved by the agency. Idaho DOT specifies that for each soil or material type, the average moisture content of at least 7 consecutive tests will be calculated to indicate the density gauge is reading the moisture content within a tolerance of 1%. If the average moisture content exceeds the 1% tolerance, a moisture correction will be applied. If less than 7 density tests are required for a specific material type, then the percent moisture will be determined by performing AASHTO T-255 (Total Moisture Content of Aggregate by Drying) or T-265 (Laboratory Determination of Moisture Content of Soils). None of the other states outline any procedures for density corrections.

**Nuclear Gauge Calibration**. The nuclear density gauge is reported to have varying degrees of reliability in providing direct measurement of the water content of soils. Many users, either due to successful experience or naivete, believe the values shown by the gauge is very similar to oven-dried moisture content test results. In some areas, this is a valid belief. However, there are areas where the nuclear density gauge may not provide direct readings that compare to an oven-dried result with an acceptable margin or error.

The nuclear density gauge measures water content from a "thermal neutron" count. When fast neutrons strike hydrogen atoms, they lose velocity and are referred to as thermal neutrons. The count of these thermal neutrons is used to determine moisture content. Many soils and aggregates are primarily formed of silica and oxygen, and therefore most of the hydrogen present in those soils would be from the water molecules occupying the void space in the soil. However, many soils whose structure contains chemically bound hydrogen, such as clays or other soils that contain mica minerals, may yield higher moisture contents when measured by a nuclear gauge then those determined by oven drying.

The calibration procedures for nuclear density often consists of calibrating the device on standard blocks of materials whose properties are standardized. If the hydrogen content of the block greatly exceeds that which would be normally expected in a soil, then the device may not be as accurate when testing materials of lower hydrogen content. One of the primary purposes of the calibration procedure is to ensure the device output is consistent when repeated measurements are taken on the same material or sets of materials. If a nuclear gauge is used to test a soil multiple times in an area where the soil type and moisture content are uniform, then the device should provide similar readings each time. If the readings do not match the oven-dried moisture content of the soil, a correction factor is required, but this is not a calibration issue. However, if the gauge provides different readings in an area where the soil type and moisture content are constant, then the gauge may be out of calibration.

With regards to correction factors, some users have collected data of the nuclear gauge output and results of oven-dried tests on the same samples. By plotting the data with the nuclear gauge reading on one axis and the oven dried (or other acceptable method) on the other axis, a linear relationship may exist. When this type of data exists, the graph may be used to determine the correction factor between the two methods. When attempting to develop such a curve, one should bear in mind that the curve is only valid for the gauge the data was collected from. The radioactive sources in each gauge may be different, and therefore each gauge may yield different results. Finally, such a curve would need to be reaccomplished each time the gauge was recalibrated.

## 5.8 Conclusions

Based on the findings of this research, a series of conclusions may be drawn with regard to soil density testing in the state of South Dakota. From these conclusions a series of implementation recommendations are developed as presented in Chapter 6.

One of the primary objectives of this research was to determine if there were any density based testing methods in use by other states that would be more efficient than the methods currently used in the state. Based on the survey results there are no such methods.

A brief investigation was conducted to review non-density based testing methods for compaction inspection. This review determined that new methods have been developed that may eliminate some of the problems associated with density based testing and establishment of target values. Of these methods, the Humboldt Stiffness Gauge appears to be the device that is most commercially viable. This device has been tested by various agencies around the country in recent years, and a new FHWA sponsored pooled study will provide a large scale field trial. It is suggested that in the coming years this device, or one similar, will replace density based testing of compacted soils.

No other density based procedure used by other states show any potential for significant increases in efficiency and it may still be a few years before new technologies find widespread acceptance. Therefore, in the interim period, efficiencies must be achieved through modification of existing procedures. These efficiencies can come through the following actions: reducing transit time between sampling locations and testing locations, reducing frequency of testing of pipe backfill soils, and make increasing use of existing nuclear gauges. Finally, it should be stated that the inspector needs to have a more visible presence on site, and current procedures prevent that.

# CHAPTER 6 RECOMMENDATIONS

During this research, current and new methods for testing compacted soil in the field were evaluated with the primary purpose of improving the efficiency of compaction testing in South Dakota. The findings of this research are presented in Chapter 5, and those findings were used as a basis for the development of the recommendations presented in this chapter.

The recommendations in this chapter were developed with two assumptions. First, that no additional personnel would be available to perform field inspections. This means all recommendations must not require additional staffing. Second, the development of alternative methods of soil compaction testing is progressing rapidly, as evidenced by recent research. These methods eliminate the need for soil density target values. With FHWA field trials of new equipment underway, new commercially viable methods may be validated and available for widespread use in three to five years. The use of these methods would require significant changes to the SDDOT materials manual within a few years.

**Recommendation One**: Avoid significant changes to the SDDOT Materials Manual.

It is the opinion of the author that the means by which we specify soil compaction will change within the next 3 to 10 years. Advances in electronic instrumentation and computing hardware and software are allowing the development of new equipment at reasonable costs. If that opinion is accepted, then the state must look at positioning itself to begin to transition to these new methods. However, as with all changes, the state must not abandon a system that has provided us with properly compacted soils until we are certain the new methods will provide equal or better results.

If the state believes that within the next three to five years new methods will be available to test soils, then significant changes to the existing procedures should not be made. This is because it may not be prudent to totally change a system before the 2001 construction season only to totally change it again three to five years later. Significant changes potentially require obtaining many pieces of new equipment, total rewriting of all testing specifications, complete retraining of all employees, and familiarizing contractors with these new methods. To go through this process twice in a three to five year period could be potentially wasteful and create more confusion than progress.

At the same time, the success of stiffness based design and testing methods is still unknown. The potential for success has clearly been documented, but the results of the FHWA pooled study must be available to make that determination.

Therefore, current soil density testing in South Dakota must be streamlined in an effort to allow technicians more time to complete their tasks. Modifications to the Materials Manual should be developed that reduce the time devoted to soil testing without radically changing existing procedures. This would help alleviate the immediate problem, while allowing the state some time to determine if the new technologies will become reality in the near future.

**Recommendation Two**: Inspectors should have vehicles equipped with density kits.

On many jobs the inspector is away from the work site because of the transit time from the test site to the field laboratory. The use of a vehicle equipped with the necessary testing equipment would allow the inspector to remain on site nearly full time and still accomplish the necessary testing. A list of the equipment and their current purchase price is listed in Appendix B. A total cost for the equipment is not given because many of the DOT labs have much of this equipment on hand. Additionally, the cost may depend on how the agency wishes to conduct the tests (i.e. sand cone vs. rubber balloon, stove-top moisture vs. speedy, etc.) Digital and mechanical scales are available that meet the accuracy requirements of the Materials Manual. Digital scales are rechargeable for field use. This recommendation provides more continuous observation of the contractor, while also providing a significant time savings to the inspector. In some cases, the time to travel to and from the field laboratory is equal to the time spent actually testing the soil. This is a repeat recommendation from SD 91-05 "Essential Testing and Inspection Levels." In the nine years since that recommendation was made, personnel reductions may justify reconsideration of this recommendation. The technical panel for project SD 91-05 stated that the idea had been tried but that the rough terrain on which the vehicles operated could cause damage to the equipment. Michigan DOT uses self-contained kits exclusively and did not report this as a problem.

**Recommendation Three**: Reduce the frequency of density testing of pipe backfill.

It is not adequate justification to make a recommendation based solely on the fact of what other states specify. However, the significance of the difference between the frequency of pipe backfill testing required in South Dakota and that of other states does suggest that South Dakota may be overtesting these soils. A summary of pipe testing frequencies by state was presented in Tables 4 and 6. Because the rationale behind the development of the testing frequencies used in SD was not discovered, it is difficult to establish how that standard was arrived at.

It is recommended that the minimum testing frequency of pipe backfill be the same as what is used for the layer into which the pipe is being placed. Therefore if the pipe is being placed in the embankment, it must be tested at the frequency specified for embankment soils. In addition, a test should be done on the soil at the base of the trench prior to placement of the pipe or any bedding material. Once again, this is a minimum testing frequency that provides the inspector a clear picture of what is necessary to achieve the desired compaction in the field. If subsequent observations of the operation indicates adequate compaction is not being achieved, the inspector is certainly able to test over and above the minimum requirement. By adopting this testing frequency, a reduction in the number of one-point tests is also achieved.

**Recommendation Four**: Allow use of microwave oven for moisture content determination.

The use of the microwave oven for moisture content testing of soils is specified by ASTM D 4643. Because of the widespread presence of microwave ovens in laboratory trailers, this method should be considered for use.

**Recommendation Five**: Develop a field guide for earthwork testing.

Although many engineers appear to feel comfortable with the SD Materials Manual, many inspectors and interns suggested that the size and wording of the manual made it an intimidating and sometimes confusing document. The Materials Manual primarily contains the frequencies and procedures for field and labs tests for soils, aggregates, asphalt, concrete, and miscellaneous materials. Much of the manual does not apply to field testing of earthwork. A smaller and concise pocket type manual, like used by the Ohio DOT, may find widespread use and acceptance in the field. This handbook contains sections on General Soils Information, General Earthwork Construction, Moisture Control and Testing, Compaction of Soils, Compaction Testing of Soils using a Nuclear gauge and Sand Cone, and a section on earthwork Inspections, Tests, Reports, Controls and Calculations. The manual provides simple step by step instructions on each of the topics. The manual would be developed to be a supplement (but not a replacement), to the Materials Manual to be used in the field.

**Recommendation Six**: Disseminate training materials to all DOT offices conducting field testing.

For the personnel who are unable to attend the annual or refresher training for soil testing, standardized materials should be widely available to all personnel conducting soil testing on DOT projects. All workbooks and presentation materials should be available to every DOT employee conducting soil testing. This would provide materials for review sessions by full time employees at the local offices and provide training aids for summer interns. Additionally, this would provide valuable information to contractors who are required to perform testing to state specifications.

**Recommendation Seven**: Increase use of existing nuclear density gauges.

The use of nuclear density gauges for soil testing varies from region to region. Although the use of the nuclear gauge does not change minimum test frequency or requirement for one-point determinations, it does allow for additional testing. Also, the project must require enough testing be performed to allow for proper determination of density and moisture correction factors. Once the target value has been established, the nuclear gauge can provide moisture density results much faster than the sand cone or rubber balloon method. Use of the nuclear gauge would allow for additional testing over and above what is currently being accomplished. Certain regions within the DOT do not get acceptable results with regard to moisture contents from the nuclear gauge, and that contact with the manufacturer has not resolved the issues. The source of these problems may be related to instrument calibration or use in soils that contain bound hydrogen. Calibration problems cause the output to be inconsistent. Proper readings in soils with bound hydrogen should be obtained with application of a correction factor. Operator training materials used in SD are consistent with those used in other states. The resolution of these issues would lead to increased confidence, and use, of the nuclear gauges.

**Recommendation Eight**: Obtain assessment of the Soil Certification Course to maintain quality instruction that meets student needs.

Personnel who have attended the SDDOT Soil Certification Course should be encouraged to provide feedback on what portions of the course are relevant to their work. In many cases evaluations are given at the end of a class. In addition, a follow up evaluation could be sent to the students at the end of the summer construction season asking their opinions on how the class was beneficial to them and if there was additional material that needed to be covered. Those responses could be evaluated prior to the offering of the next Soil Certification Class so that changes could be made before the start of the next class.

**Recommendation Nine**: Conduct extensive evaluations of the Humboldt Geo Gauge.

During the 2001 construction season, the SDDOT has chosen to participate in the FHWA pooled study to evaluate the Humboldt GeoGauge™. This device, if successful, could be the tool that allows the state to eliminate the most burdensome and time consuming tasks related to testing of compacted soils. The state should use the device to the maximum extent possible this summer in a series of side by side tests with existing methods to determine the effectiveness, time savings, applicability to all South Dakota soils, training, and support. From this extensive use, the state could decide if this device is suitable for use. This way the state could forge ahead without having to rely solely on the results of the pooled study, whose results may not be available in time to make revisions and decisions prior to the 2002 construction season.

**Recommendation Ten**: Use existing state data to determine validity of the Ohio family of Curves.

Of the 10 soils tested as part of this research, three were not represented within the allowable standards by the Ohio family of curves. Because this research used a limited set of test data, conclusions as to the validity of the Ohio curves can not be drawn at this time. If a significant number of 4-point curves are available from the materials engineers within the State, then this data should be collected and used to evaluate the validity of the Ohio curves for South Dakota, or, if necessary, develop a new family of curves.

# REFERENCES

"Annual Book of ASTM Standards, Volume 4.08, Soil and Rock," American Society For Testing and Materials, West Conshohocken, PA, 1998.

"Compaction Inspector Programmed Instruction Manual," West Virginia Division of Highways, Charleston, WV, 2000.

"Embankment & Base In-Place Density Instructor Guide," Western Alliance for Quality Transportation Construction, Boise, ID, 1998.

"Guide to Earthwork Construction," National Research Council, Transportation Research Board, Publication No. FHWA-HI-90-048, Washington, DC, 1990.

"Guide Instruction Manual For Inspectors of Earthwork and Base Course Construction," South Carolina Department of Transportation, Columbia, SC, 2000.

Liu, C. and Evett, J.B., "Soil Properties Testing, Measurement, and Evaluation, 3rd Edition, Prentice Hall, New Jersey, 1997.

McCarthy, D.F., "Essentials of Soil Mechanics and Foundations," 4th Edition, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1993.

Monahan, E.J., "Construction of Fills," 2nd Edition, John Wiley and Sons, New York, 1994.

"SDDOT Standard Specifications for Roads and Bridges," South Dakota Department of Transportation, Pierre, SD, 1998.

"SDDOT Materials Manual," South Dakota Department of Transportation, Pierre, SD, 2000.

"Soil Stiffness Gauge for Soil Compaction Control," Public Roads, Volume 61, No. 5, March/April 1998, pp. 5-10.

"Standard Specifications For Construction of Roads and Bridges On Federal Highway Projects," FP-96, Federal Highway Administration, Washington, DC, 1996.

"Standard Specifications for Transportation Materials and Methods of Sampling and Testing," American Association of State Highway and Transportation Officials, 15th Edition, Washington, DC, 1990.

"Standard Specifications for Roads and Bridges," West Virginia Division of Highways, Charleston, WV, 2000.

"Technician Qualification Program (Soils and Aggregates) Participant's Manual," University of Tennessee, Department of Civil and Environmental Engineering, Knoxville, TN, 2000.

"Test Method For Earthwork Compaction Control By Nuclear Gauge," STM-10, New York State
Department of Transportation, Soil Mechanics Bureau, Albany, NY, 1981.

Woods, K.B. and Litehiser, R.R., "Soil Mechanics Applied to Highway Engineering in Ohio," College of Engineering, Ohio State University, Columbus, July, 1938.

# APPENDIX A: DRAFT CHANGES TO SDDOT MATERIALS MANUAL

Section "Minimum Sample & Test Requirements"

With respect to pipe backfill,

**Section 4.1.D is suggested to read as follows**:

D. Pipe Backfill (Includes Box Culverts).

Note: The definition of "per installation" as shown for density tests shall be:

One or more pipes at one site when backfill is placed uniformly around all pipes and compactive effort is uniform around each pipe.

(1) Tier not applicable

(2) Certification.

Not required.

(3) Acceptance.

(a) Cross, Storm Sewer, Sanitary Sewer, and Water Main Pipe

1. Minimum Requirements per Installation in Embankment or Berm.

a. One per ½ mile (800 m), per installation, per zone, with a minimum of three tests per ½ mile (800 m). The zones are defined in item 3 under "Reductions of 1-Point Determinations" in the General Notes for this section. (DOT-41)

With respect to Granular Box Culvert Undercut Backfill,

**Section 3.10 B. (3) is suggested to read as follows**:

(3) Acceptance.

One per ½ mile, to ensure that the required density is being obtained with the equipment and procedure being used. (DOT-41)

NOTE: Where insulating board is used, the density shall be taken in the lift below it.

Section "100 Soils" – Section 108 "Moisture Content Determination"

**Insert the following procedures for microwave testing of soils.**

2.6 Microwave Moisture Test

A. Microwave oven (preferable with a vented chamber and variable power controls; input power ratings of 700 W are adequate)

B. Scale with a capacity of at least 2000 g sensitive and readable to 0.1 g.

C. Containers (must be suitable for microwave ovens – i.e., nonmetallic and resistant to sudden and extreme temperature change; porcelain, or glass.

D. Stirring tool or Trowel.

E. Gloves.

3.6 Microwave Method

A. Determine the mass of a clean, dry container or dish, and record.

B. Place the soil specimen in the container, and immediately determine and record the mass.

C. Place the soil and container in a microwave oven and turn the oven on for 3 min. If experience with a particular soil type and specimen size indicates shorter or longer initial drying times can be used without overheating, the initial and subsequent drying times may be adjusted.

Note: The 3-min. initial setting is for a minimum sample mass of 100 g. Smaller samples are not recommended when using the microwave oven because drying may be too rapid for proper control. Large samples may need to be split into segments and dried separately to obtain the dry mass of the total sample.

Most ovens have a variable power setting. For the majority of soils tested, a setting of “high” should be satisfactory; however, for some soils such a setting may be too severe. The proper setting can be determined only through the use of and experience with a particular oven for various soil types and sample sizes. The energy output of microwave ovens may decrease with age and usage; therefore, power settlings and drying times should be established for each oven.

D. After the set time has elapsed, remove the container and soil from the oven, either weigh the specimen immediately, or place in a desiccator to cool to allow handle and to prevent damage to the balance. Determine and record the mass.

E. With a small spatula, knife, or short length of glass rod, carefully mix the soil, taking special precaution not to lose any soil.

F. Return the container and soil to the oven and reheat in the oven for 1 min.

G. Repeat (D) through (F), until the change between two consecutive mass determinations would have an insignificant effect on the calculated moisture content. A change of 0.1% or less of the initial wet mass of the soil should be acceptable.

H. Use the final mass determination in calculating the water content. Obtain this value immediately after the heating cycle as soon as the container may be handled safely.

# APPENDIX B: DENSITY KIT EQUIPMENT

1 – Volumeter w/base plate and pressure gauge ($384.00)

1 – Box of Spare Balloons ($8.00)

1 – Standard Proctor Rammer ($53.00)

1 – Proctor Mold ($69.00)

1 – Strike-off Bar ($15.00)

2 – 18 in. x 18 in. pans ($33.00 each)

1 – Large 12 in. spoon ($5.00)

1 – "Speedy" Moisture Tester Kit ($1,195.00)

1 – 4 in. spatula ($6.00)

1 – 8 x 8 by 10 inch wooden pounding block

1 – 18 by 26-inch screen with ¼ inch mesh ($113.00)

1 – Digital Field Scale w/recharger & carrying case (20 kg capacity & reads to 1 g)($610.00)

1* – Nuclear gauge and support equipment ($6,000.00)

**Additional Equipment Needed When a Stove is Used**

1 – Field Stove (propane - $78.00; unleaded gas – $81.00)

1 – Digital Field Scale w/ recharger (1200 g capacity & reads to 0.1g)($350.00)

2 – Frying pans ($35.00 each)

4 – Moisture Cans ($12.00)

**Alternative Equipment Choices**

1 – Mechanical Scale (2610 g capacity and reads to 0.1 g)($162.00)

1 – Mechanical Solution Balance (20 kg capacity and reads to 1 g)($985.00)

1 – Sand Cone w/base plate ($84.00 each)

* if necessary

# APPENDIX C: COMPARISON TABLES OF TEST DATA TO OHIO CURVES

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| Test | Lab Data (T-99) | | Ohio Curve @ -3% OMC | | | Ohio Curve @ -2% OMC | | | Ohio Curve @-1% OMC | | | Ohio Curve @ +1% OMC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OMC | γ max (pcf) | Curve Letter | OMC | γ max (pcf) | Curve Letter | OMC | γ max (pcf) | Curve Letter | OMC | γ max (pcf) | Curve Letter | OMC | γ max (pcf) |
| 1 | 11.6 | 134.5 | off scale | | | I | 11.9 | 136.2 | I | 11.9 | 136.2 | K | 13.5 | 132.8 |
| 2 | 9.9 | 142.6 | e | 9.3 | 142.9 | e | 9.3 | 142.9 | e | 9.3 | 142.9 | D | 8.5 | 145.5 |
| 3 | 12 | 141.1 | G | 10.5 | 139.9 | g | 10.8 | 138.9 | g | 10.8 | 138.9 | D | 8.5 | 145.5 |
| 4 | 30.2 | 113.8 | X | 30.5 | 110.9 | w | 30.0 | 112.2 | W | 29.5 | 113.3 | W | 29.5 | 113.3 |
| 5 | 21.3 | 120.3 | S | 22.7 | 119.5 | k | 14.0 | 132.0 | k | 14.0 | 132.0 | l | 15.2 | 130.5 |
| 6 | | | | | | | | | | | | | | |
| 7 | 15.7 | 128.5 | O | 18.1 | 126.5 | n | 17.5 | 127.3 | k | 14.0 | 132.0 | l | 15.2 | 130.5 |
| 8 | 13.6 | 131.1 | L | 14.6 | 131.3 | k | 14.0 | 132.0 | k | 14.0 | 132.0 | l | 15.2 | 130.5 |
| 9 | 10 | 127.8 | i | 12.3 | 135.3 | i | 12.3 | 135.3 | i | 12.3 | 135.3 | j | 13.1 | 133.6 |
| 10 | 11.6 | 130.2 | K | 13.5 | 132.8 | j | 13.1 | 133.6 | j | 13.1 | 133.6 | K | 13.5 | 132.8 |
| 11 | 19.3 | 125.9 | P | 19.2 | 124.8 | P | 19.2 | 124.8 | P | 19.2 | 124.8 | O | 18.1 | 126.5 |

**Table 7 List of Ohio Curves Corresponding to Data Points From Laboratory T-99 Tests**

| | Percent Below OMC From Lab Data | | | | |
|---|---|---|---|---|---|
| | -3 | -2 | -1 | +1 | Average Difference |
| Test 1 | Off Curve | 1.7 | 1.7 | 1.7 | 1.7 |
| Test 2 | 0.3 | 0.3 | 0.3 | 2.9 | 0.95 |
| Test 3 | 1.2 | 2.2 | 2.2 | 4.4 | 2.5 |
| Test 4 | 2.9 | 1.6 | 0.5 | 0.5 | 1.4 |
| Test 5 | 0.8 | 11.7 | 11.7 | 10.2 | 8.6 |
| Test 6 | No Data | | | | |
| Test 7 | 2.0 | 1.2 | 3.5 | 2.0 | 2.2 |
| Test 8 | .02 | 1.9 | 1.9 | 0.6 | 1.2 |
| Test 9 | 7.5 | 7.5 | 7.5 | 5.8 | 7.1 |
| Test 10 | 2.6 | 3.4 | 3.4 | 2.6 | 3.0 |
| Test 11 | 1.1 | 1.1 | 1.1 | 0.6 | 1.0 |
| Average Difference | 2.1 | 3.3 | 3.4 | 3.1 | |

**Table 8 Difference Between Actual $\gamma_{max}$ From Lab Data and $\gamma_{max}$ From Ohio Curve**

| | Percent Below OMC From Lab Data | | | | |
|---|---|---|---|---|---|
| | -3 | -2 | -1 | +1 | Average Difference |
| Test 1 | Off Scale | 0.3 | 0.3 | 1.9 | 0.83 |
| Test 2 | 0.6 | 0.6 | 0.6 | 1.4 | 0.8 |
| Test 3 | 1.5 | 1.2 | 1.2 | 6.5 | 2.6 |
| Test 4 | 0.3 | 0.2 | 0.7 | 0.7 | 0.48 |
| Test 5 | 1.4 | 7.3 | 7.3 | 6.1 | 5.5 |
| Test 6 | No Data | | | | |
| Test 7 | 2.4 | 1.8 | 1.7 | 0.5 | 1.6 |
| Test 8 | 1.0 | 0.4 | 0.4 | 1.6 | 0.85 |
| Test 9 | 2.3 | 2.3 | 2.3 | 3.1 | 2.5 |
| Test 10 | 1.9 | 1.5 | 1.5 | 1.9 | 1.7 |
| Test 11 | 0.1 | 0.1 | 0.1 | 1.2 | 0.38 |
| Average Difference | 1.3 | 1.6 | 1.6 | 2.2 | |

**Table 9 Difference Between Actual OMC From Lab Data and OMC From Ohio Curve**

# APPENDIX D: SDDOT FORM DOT-41

DOT-41
( 2/99 )

**DENSITY REPORT**

SOILS OR GRANULAR

COUNTY ____________ PROJECT ____________ PCEMS ________ FILE NO. ________

STATION ____________ DIST. FROM CL ____________ RT or LT WIDTH (Gravel) ____________

DEPTH ________ (from top of Subgrade or Pipe) (Hole - Gravel) TEST NO.________ (EMBANKMENT) (BERM) (PIPE) (BASE COURSE) (SUBBASE)

TESTED BY ____________ CHECKED BY ____________ DATE ____________

**WORK AREA REPRESENTED** (Circle what applies)

**EMBANKMENT** STA. TO STA. ____________ (per half mile/800 m, for each roadbed)

Zone 1(0-1ft./0-300mm) Zone 2(1-3 ft./300-900mm) Zone 3(3-5 ft./900-1500mm) Zone 4(5 ft./1500mm to base, 1 per 5 ft./1500mm)

**BERM** STA. TO STA. ____________ (100 ft./30 m from Bridge End)

Zone 1(0-1ft./0-300mm) Zone 2(1-3 ft./300-900mm) Zone 3(3-5 ft./900-1500mm) Zone 4(5 ft./1500mm to base, 1 per 5 ft./1500mm)

**PIPE**

| | | | | | | |
|---|---|---|---|---|---|---|
| CROSS | 24"/600mm or Smaller | Undercut | (½ way up) | (2'/600mm Above) | | |
| STORM | 30"/750mm to 72"/1800mm | Undercut | (Lower ½ ) | (Upper ½ ) | (2'/600mm Above) | |
| INTERSECTION | 72"/1800mm or More | Undercut | (Bottom 1/3) | (Middle 1/3) | (Top 1/3) | (2'/600mm Above) |

After Minimum for size pipe installation ( )1 per 3 ft./900mm of backfill beginning at 2'/600mm above top of pipe

**SUBBASE** STA. TO STA. ____________ LIFT ________ (per mile (1600 m), per lift, per roadbed)

**BASE COURSE** STA. TO STA. ____________ LIFT ________ (per mile (1600 m), per lift, per roadbed)

| CURVE USED | 1-POINT MAXIMUM DENSITY | OPTIMUM MOISTURE | GRANULAR MATERIAL 4-POINT RANGE | SPECIFICATION ________ % |
|---|---|---|---|---|
| ________ | U. ________ | ________ % | ________ TO ________ | % OBTAINED ________ % 100 x (G/U) |

| BALLOON METHOD | | SAND METHOD | | NUCLEAR METHOD | |
|---|---|---|---|---|---|
| | | | | METER NO. ________ DEPTH | |
| | | A. STD. SAND PCF OR kg/m$^3$ | | TEST MODE ________ | |
| B. WT. UNDRIED MATL. FROM HOLE | | B. WT. UNDRIED MATL. FROM HOLE | | A. STANDARD COUNT | |
| C. VOLUMETER READING IN HOLE | | C. INITIAL WT. SAND | | B. DENSITY COUNT | |
| D. INITIAL VOLUMETER READING | | D. FINAL WT. SAND PLUS CONE SAND | | D. DENSITY COUNT RATIO ( B / A ) | |
| E. VOLUME OF TEST HOLE ( C - D ) [ x 0.028317 METRIC ] | | E. VOLUME OF TEST HOLE ( C - D ) / A [ / 1000 FOR METRIC] | | F. WET DENS. FROM METER OR CHART ________ ± CORR. * ________ = | |
| F. WET DENSITY ( B / E ) [ / 1000 METRIC ] | | F. WET DENSITY ( B / E ) [ / 1000 METRIC ] | | | |
| G. DRY DENSITY F / ( 100 + M ) x 100 | | G. DRY DENSITY F / ( 100 + M ) x 100 | | G. DRY DENSITY ( F - K ) (K from Nuclear Field) | |

| STANDARD DENSITY DETERMINATIONS (1-POINT) | | MOISTURE DETERMINATIONS | 1 - POINT | FIELD | NUCLEAR METHOD | FIELD |
|---|---|---|---|---|---|---|
| O. WEIGHT OF MOLD & SPECIMEN | | H. WT. OF WET MATL. AND CONTAINER | | | H. STANDARD MOIST. COUNT | |
| P. WEIGHT OF MOLD | | I. WT. OF DRY MATL. AND CONTAINER | | | I. MOISTURE COUNT | |
| Q. WET WEIGHT OF MOLDED MOLDED SPECIMEN ( O - P ) | | J. WT. OF MOISTURE ( H - I ) | | | J. MOIST. COUNT RATIO ( I / H ) | |
| R. FACTOR OF MOLD No. ________ USED IN TEST | | K. WT. OF CONTAINER | | | K. MOIST kg/m$^3$ OR PCF FROM METER OR CHART ±CORR.★ ________ = | |
| S. WET DENSITY ( Q x R ) [ / 1000 FOR METRIC ] | | L. WT. OF DRY MATL. ( I - K ) | | | | |
| T. DRY DENSITY S/(100+M [1-PT]) X 100 | | M. PERCENT MOISTURE FIELD ( J x 100 ) / L | | | M. PERCENT MOISTURE FIELD ( K x 100 ) / G | |

★ CORRECTION FROM DOT-39. IF THERE IS NO CORRECTION OR, IF THE CORRECTION HAS BEEN APPLIED TO THE METER SHOW "NA".

NOTE: IF MOISTURE CORRECTION IS A PLUS ( + ), A NEW CORRECTION MUST BE COMPUTED FOR EACH TEST

**1-POINT NOT MADE THIS TEST, REFER TO** MOISTURE TEST NO. ________ or DENSITY TEST NO. ________

**COMMENTS:** ____________