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Lightweight Deflectometer for Quality Assurance of Compacted Sublayers and Earthwork

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This report documents and presents the results of a study for implementation of lightweight deflectometer (LWD) testing for construction Quality Assurance (QA) in Alaska. The research evaluated empirical values, control strip testing, and laboratory testing to determine LWD target values. The results indicate control strip testing is the preferred method for determining LWD-TVs in Alaska at this time. Test results indicate either elastic modulus or deflection can accurately provide acceptance criteria for unbound materials, but Alaska Department of Transportation and Public Facilities prefers deflection because it is directly measured by all LWD devices and more intuitive to communicate with contractors, inspectors, and technicians. This research develops standard test methods, modifications to Alaska Standard Specifications, and training materials to facilitate implementation of LWD testing for QA.

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ABSTRACT

This report documents and presents the results of a study for implementation of lightweight deflectometer (LWD) testing for construction Quality Assurance (QA) in Alaska. The research evaluated empirical values, control strip testing, and laboratory testing to determine LWD target values. The results indicate control strip testing is the preferred method for determining LWD-TVs in Alaska at this time. Test results indicate either elastic modulus or deflection can accurately provide acceptance criteria for unbound materials. The Alaska Department of Transportation and Public Facilities prefers deflection because it is directly measured by all LWD devices and more intuitive to communicate with contractors, inspectors, and technicians. This research develops standard test methods, modifications to Alaska Standard Specifications, and training materials to facilitate implementation of LWD testing for QA.

EXECUTIVE SUMMARY

The State of Alaska Department of Transportation and Public Facilities (DOT&PF) currently utilizes relative density as the performance measure for construction Quality Assurance (QA). However, density is a material property that serves as a proxy for other engineering properties used in design of roadways and airfields. The lightweight deflectometer (LWD) provides an alternative performance measure for QA that directly measures engineering properties of materials. The DOT&PF wants to transition from a density-based approach for QA to an LWD-based approach but lacks the appropriate LWD methods and specifications, experience with LWD devices, and training for their technicians.

The objectives of this research included:

- Evaluating the application of LWD testing for QA in Alaska
- Developing the standards needed to implement use of LWDs for QA
- Developing training materials to support implementation

Research results indicate that LWDs can successfully test unbound Alaska materials for acceptance. Three techniques are available for determining the target values for acceptance testing, including empirical values, control strip testing, and laboratory testing. Alaska's limited LWD data precludes using empirical values and laboratory testing is impractical at this time. Therefore, the DOT&PF prefers control strip testing.

The research scope included development of Alaska Test Method (ATM) 310 *Relative LWD Deflection of Embankment Materials by the Control Strip Method* (ATM 310) and modifying the DOT&PF Standard Specifications for Highway Construction (Standard Specifications) to support implementation of LWD testing for QA. ATM 310 and the specification modifications use a deflection criteria rather than modulus criteria due to the ease of data collection and communication with contractors, inspectors, and technicians.

Implementation of LWD testing for QA will improve the quality of Alaska's infrastructure, reduce nuclear moisture-density gauge related costs, eliminates DOT&PF employees' potential radiation exposure, and eliminates the risk of potential accidents involving radiation exposure.

CHAPTER 1 – BACKGROUND

Stiffness, not density, of materials used in the pavement structural section links design with real-world pavement performance. For decades, construction acceptance and Quality Assurance (QA) testing of unbound materials during construction has relied on density measurements of compacted soils and aggregates taken with a nuclear moisture-density gauge. However, Lightweight Deflectometers (LWD) are increasingly recognized by the construction industry as a superior method for QA.

LWDs can directly measure deflection and elastic modulus of unbound materials and provide an actual correlation to material performance. Overcoming challenges, including the lack of LWD methods and specifications for implementation, as well as differences in LWD devices themselves, is crucial for achieving this synergy. DOT&PF is moving to overcome the Alaska-specific challenges, including the use of a wide variety of standard and non-standard material types, regional variations specified material types, extreme weather, and remote locations.

Problem Statement

The State of Alaska Department of Transportation and Public Facilities (DOT&PF) currently utilizes relative density as the performance measure for QA. It is common engineering knowledge that density is a poor approximation for resilient modulus and, therefore, pavement performance. For example, the Iowa Department of Transportation demonstrated a deficiency in the performance of their pavements when using relative density for quality assurance. Plate load testing measurements in the state of Iowa indicate that only 30% of the tested locations meet the resilience modulus values assumed in design (Ingios Geotechnics 2023) when QA uses density based methods. As a result, Iowa is in the process of implementing modulus-based requirements and field methods

The nuclear moisture-density gauges not only have a poor correlation to performance but also have significant costs for NRC licensing, upkeep, usage, transport, and storage, as well as posing a significant safety concern and accident risk. The DOT&PF estimates that they spend more than $250,000 per year on nuclear moisture-density gauge related expenses.

The DOT&PF wants to transition from a density-based standard for QA to a deflection-based standard by leveraging LWD technology, methods, and standards used by other states. DOT&PF currently is developing the appropriate standard methods and specifications, experience with LWD devices, and training for their technicians.

Research Objective

The objectives of this research included:

- Evaluating the application of LWD testing for QA in Alaska
- Developing the standards needed to implement use of LWDs for QA
- Developing training materials to support implementation

LWD testing will increase the quality and service life of Alaska’s roads and airports by providing a better measurement of product performance. Application of LWD devices eliminates the significant expense of maintaining the required licensing for nuclear moisture-density gauges. Further, LWD devices are easy to transport throughout Alaska. LWD’s do not classify as hazardous material, allowing transport on passenger flights. While the upfront cost of obtaining LWD devices is an investment, the cost of annual maintenance and calibration will be a fraction of the current costs for nuclear moisture-density gauges.

Using LWD devices also increases the safety for DOT&PF and contractor personnel by removing the safety concerns and precautions required for nuclear moisture-density gauges.

Scope of Study

The study pursued the following key items to support its objectives:

- Pilot testing field methods
- Pilot testing laboratory methods
- Creating an Alaska Test Method (ATM) for LWD testing
- Providing modifications to the DOT&PF Standard Specifications for Highway Construction to support LWD testing
- Developing training materials

CHAPTER 2 – RESEARCH APPROACH

We divided the research into several parts to address the challenges of using LWDs for QA and achieve the research objectives. The list below identifies and outlines these parts:

1. Literature Review
2. Preliminary Methods Development
3. Field Testing
4. Laboratory Testing
5. Data Analysis
6. Methods Refinement
7. Reporting

The following sections provide additional details on the approach used for the research.

Literature Review

In this part of the research, HDL focused on compiling and reviewing the relevant literature necessary to inform the development of the preliminary LWD methods. Appendix A provides summaries and excerpts of the relevant literature. Additionally, representatives from the Minnesota and Indiana DOTs met with HDL and DOT&PF staff to discuss the implementation of LWD testing for QA in their respective states.

Preliminary Methods Development

We used information from the literature review to develop preliminary field and laboratory methods. The preliminary field methods generally followed the Minnesota Pilot Lightweight Deflectometer Deflection Method and the Indiana Field Determination of Deflection Using Lightweight Deflectometer, while incorporating modifications to suit the needs of DOT&PF. Laboratory test methodologies generally followed the published work of Dr. Sadaf Khosravifar. See Appendix B for the field method and the preliminary laboratory test methodology developed as part of this project.

LWD testing for QA requires the following three key steps:

1. Establish the target value (LWD-TV) for the material to be tested
2. Conduct LWD testing
3. Determine on-grade acceptance

Design engineers can establish project or material source specific LWD-TVs using empirically determined target values, control strip testing, or laboratory testing. The empirically based approach requires a significant database of LWD tests on consistent materials in order to establish LWD-TVs based on prior data and experience. Alaska does not currently have enough data on the vast number of variable materials across the state to support this method.

The control strip test provides a method for determining the LWD-TV in the field. Utilizing a compaction method (usually a roller) and an LWD, the technician can determine the amount of compaction required to achieve the LWD-TV.

Laboratory techniques establish the LWD-TV by conducting LWD tests on material compacted in a proctor mold. The analysis of the laboratory data includes a multivariate regression and subsequent calculations in the field to establish the LWD-TV.

Once the LWD-TV is determined, the technician compares future tests on-grade to the LWD-TV to determine acceptance. Application of the target value is similar to application of the maximum dry density determined by the proctor curve for nuclear moisture-density gauge testing. If deflection is used for the LWD-TV, any deflection measurements on-grade that do not exceed 120% of the LWD-TV are considered passing. If the measured deflection is greater than 120% of the LWD-TV, then the material fails and the contractor must complete additional compaction.

The literature review and preliminary test method development led to the following questions:

- Is LWD testing applicable for QA in Alaska?
- What method(s) should DOT&PF use to establish the LWD-TV?
- Should DOT&PF use elastic modulus or deflection as the value of interest?
- How does moisture content affect LWD test results for Alaska soils?

As part of this research, we conducted pilot testing for LWD field and laboratory methods to help answer these questions.

Field Testing

We conducted pilot testing in the summer of 2022 on two DOT&PF projects: the Airport Way West Improvements (Airport Way) project in Fairbanks and the Ekwok Airport Rehabilitation (Ekwok) project. We generally followed the field procedure recommended in this report, which consists of the following four steps:

1. Perform control strip testing
2. Determine LWD-TVs
3. Conduct LWD on-grade testing
4. Apply LWD-TVs to on-grade acceptance

However, the following modifications from the recommended procedure occurred during the pilot testing:

Modification 1: The research team conducted control strip testing for the crushed asphalt base course (CABC) only. We collected data for the other materials to evaluate their properties and build reference values for future use. For DOT&PF Northern Region, CABC consists of a mixture of recycled asphalt and Base Course, Grading D-1. For DOT&PF Central and Southcoast Regions, CABC is usually know as crushed aggregate base course and consists only of Base Course, Gradation D-1.

Modification 2: HDL collected more LWD test data than required by the recommended testing frequency to increase the number of tests in the database for future reference.

Modification 3: The Airport Way and Ekwok project contracts required nuclear moisture-density gauge testing for QA, so acceptance did not rely on the LWD tests in application.

Modification 4: This research conducted parallel nuclear moisture-density gauge tests for comparison to the current standard method.

Modification 5: We used two LWD devices at each test location and recorded both deflection and elastic modulus for analysis.

We performed the following tasks to collect data to support this research:

Task 1: Completed testing with two LWD devices, the Dynatest 3032 and the Zorn ZFG 3000.

Task 2: Collected and compiled elastic modulus and deflection data from both LWD devices.

Task 3: Completed parallel tests with the LWD devices and a nuclear moisture-density gauge.

Task 4: Tested four materials, Airport Way Selected Material Type A (Borrow A), CABC, and Subbase, Grading F (Subbase F) and Ekwok Crushed Aggregate Surface Course (CASC). See Appendices C, D, E, and F for the current Standard Specifications and a representative grain size distribution curve for each material tested.

See Appendix B for the field method used during on-grade testing.

Laboratory Testing

We used Selected Material Type A (Borrow A) and CABC from the Airport Way project to evaluate using laboratory testing to determine the LWD-TVs. The standard process requires determining the LWD-TV in the laboratory prior to QA testing on-grade. However, for the purpose of this research, we completed the laboratory testing during the fall and winter of 2022 after completing on-grade testing.

The load plate for the Zorn LWD device was too large to fit in the modified proctor mold and this study only used the Dynatest LWD device for laboratory testing.

The laboratory testing included the following generalized steps:

1. Compact material in a proctor mold
2. Perform LWD testing on the compacted material
3. Perform multivariate regression and post testing calculations

The technician compacts the material in accordance with American Society for Test Methods (ASTM) D1557 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort). The technician then performs LWD testing on top of the final lift by carefully centering the load plate inside the profile of the proctor mold.

The subsequent analysis of the deflection or elastic modulus values collected at each proctor point includes a multivariate regression and subsequent calculations in the field to determine the LWD-TV. The calculation analysis includes the following generalized steps:

1. Compact the materials per ASTM D1557
2. Calculate the applied plate pressure at each drop height
3. Perform multivariate regression analysis of laboratory measured modulus to determine the regression coefficients for pressure and moisture
4. Use the plate pressure and the in-situ moisture content measured on-grade, and the regression coefficients to calculate the target modulus for each test
5. Determine if the modulus measured on-grade is greater than the calculated target modulus

The technician can use the LWD-TV developed from the laboratory tests and regression to determine acceptance of on-grade tests. The on-grade testing procedure is the same as discussed in the previous section.

See Appendix B for the complete preliminary laboratory testing method. See Appendices C and D for the results of the laboratory testing and calculations for the CASC and Borrow A.

Data Analysis

After completing field and laboratory testing, the research team analyzed the LWD results. Data analyses primarily consisted of creating graphical representations of field and laboratory data, comparing LWD-TV and on-grade measurements, and laboratory calculations.

We created graphical representations of the data for the comparison of multiple variables, including:

- Material types
- Zorn and Dynatest LWD devices
- Deflection and modulus values
- Moisture content
- On-grade test values
- Control strip LWD-TVs and laboratory LWD-TVs
- LWD and nuclear moisture-density gauge results

Chapter 3 presents a summary of the analysis results. See Appendices C, D, E, and F for complete tables and plots of the analyzed data for each material.

Methods Refinement

After the pilot testing and the data analysis, we refined the preliminary procedures and created ATM 310. We also drafted modifications to the Standard Specifications to facilitate the use of LWD testing for QA. The research team and DOT&PF determined the laboratory testing multivariate regression and subsequent field calculation too cumbersome to warrant refinement of the laboratory testing at this time. Alaska has insufficient data to support the use of empirically based target values at this time and further process refinement is not warranted at this time.

See Appendix B for ATM 310 and the modifications to the Standard Specifications.

Reporting

<u>Reporting Forms</u>

As part of this study, we created reporting forms to accompany the Standard Specification modifications and ATM 310. In addition, we created, but did not refine preliminary reporting forms for the laboratory testing. See Appendix G for the reporting forms.

<u>Training Materials</u>

To achieve the DOT&PF's goal of familiarizing their staff with LWD devices and methods, Appendix H presents a written training checklist and slideshow presentation. The written training checklist provides a useful resource for the material technicians to bring with them to the field for reference. This training checklist includes required materials, an LWD quick start guide, set-up diagrams, and helpful tips.

The slideshow presentation supports classroom instruction where an experienced LWD user teaches technicians the proper procedures, safety information, and reasoning for utilizing LWD devices in QA.

See Appendix H for the training materials.

Research Report

The final step in the study consisted of developing this report.

CHAPTER 3 – FINDINGS

Airport Way CABC

The following sections present the control strip, laboratory testing, and on-grade testing performed on the Airport Way CABC material.

<u>Control Strip</u>

Figure 1 shows the deflection and modulus values measured with the Zorn and Dynatest LWDs after each roller pass during the control strip test. The DOT&PF rover ended the test after seven (7) passes because the results indicated that compaction was damaging the material and further effort would decrease density. The results presented in Figure 1 also support that conclusion since the deflection increased and modulus decreased with continued compaction. In the box and whisker plots below, the "X" denotes the mean of the data set and the line inside the box denotes the median.

Figure 1. CABC Control Strip Roller Pass Results

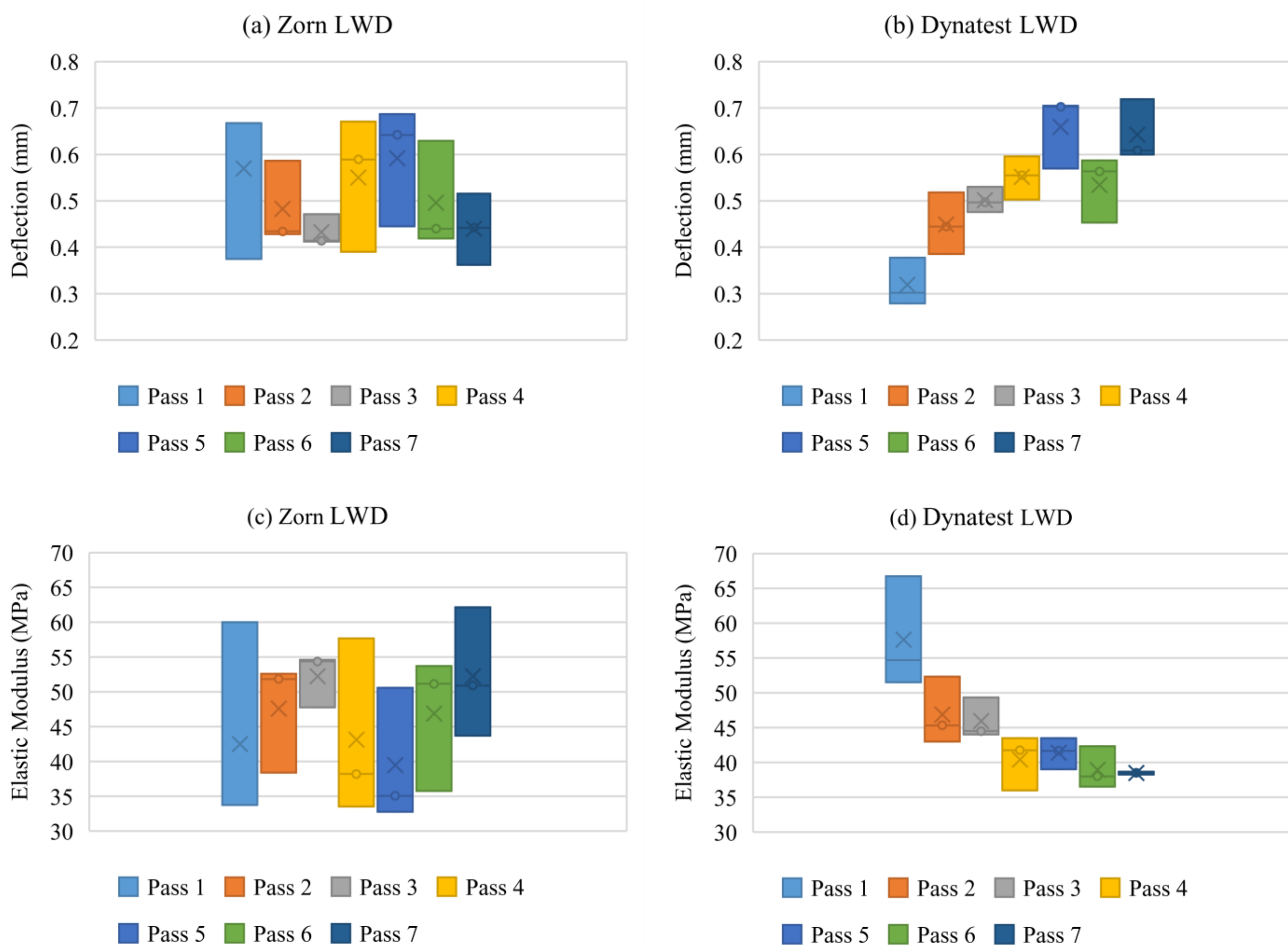


Figure 2 presents the deflection and elastic modulus values measured with the Zorn and Dynatest LWD devices compared with the measured dry density measured with a nuclear moisture-density gauge during the control strip test.

Figure 2. CABC Control Strip Results

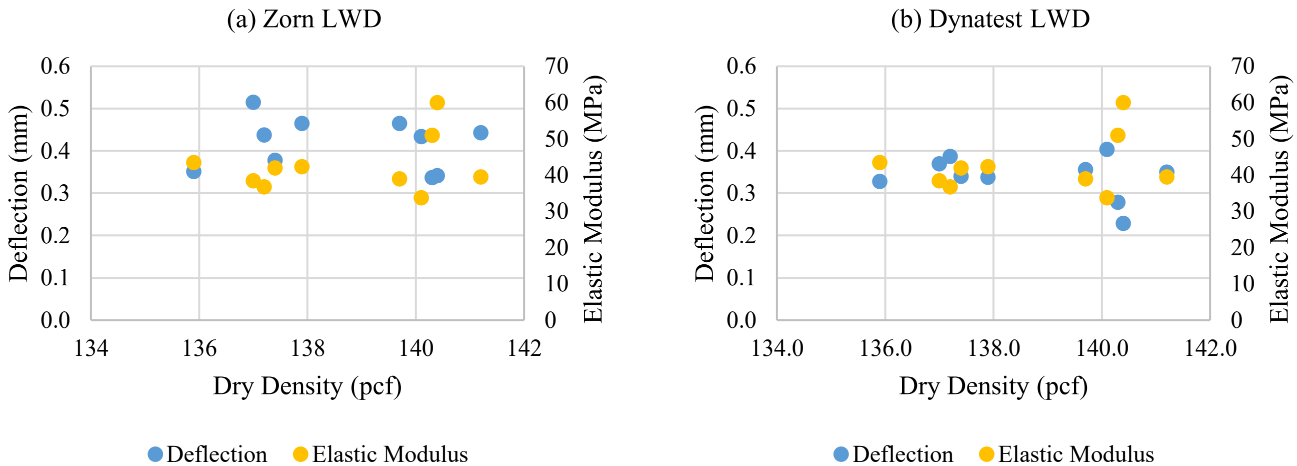


Table 1 summarizes the LWD-TVs established using the control strip.

Table 1. Control Strip LWD-TVs

Device	Criteria	Target Value Name	Value
Zorn	Deflection	LWD-TV_{zd}	0.50 mm
	Modulus	LWD-TV_{zm}	47 MPa
Dynatest	Deflection	LWD-TV_{dd}	0.41 mm
	Modulus	LWD-TV_{dm}	34 MPa

The nomenclature includes subscripts for device and method specific LWD-TVs in this chapter as appropriate. Where no subscript is included, the discussion refers to LWD-TVs in general rather than a specific device or method.

Figure 3 presents the CABC elastic modulus and deflection values measured on-grade compared to the measured dry density. The vertical red lines in the figures correspond to the density acceptance criteria (95% of the maximum dry density). Other states use ≥ 80% of the LWD-TV as the acceptance criteria for modulus values and ≤ 120% of the LWD-TV as the acceptance criteria for deflection values. For reference, the horizontal red lines in Figures 3a and 3b correspond to the calculated minimum LWD acceptance values (80% of the LWD-TV) for elastic modulus using the control strip results and the horizontal red lines in Figures 3c and 3d correspond to the calculated maximum LWD acceptance values (120% of the LWD-TV) for deflection using the control strip results.

Figure 3. CABC On-Grade Test Results with Control Strip LWD-TV

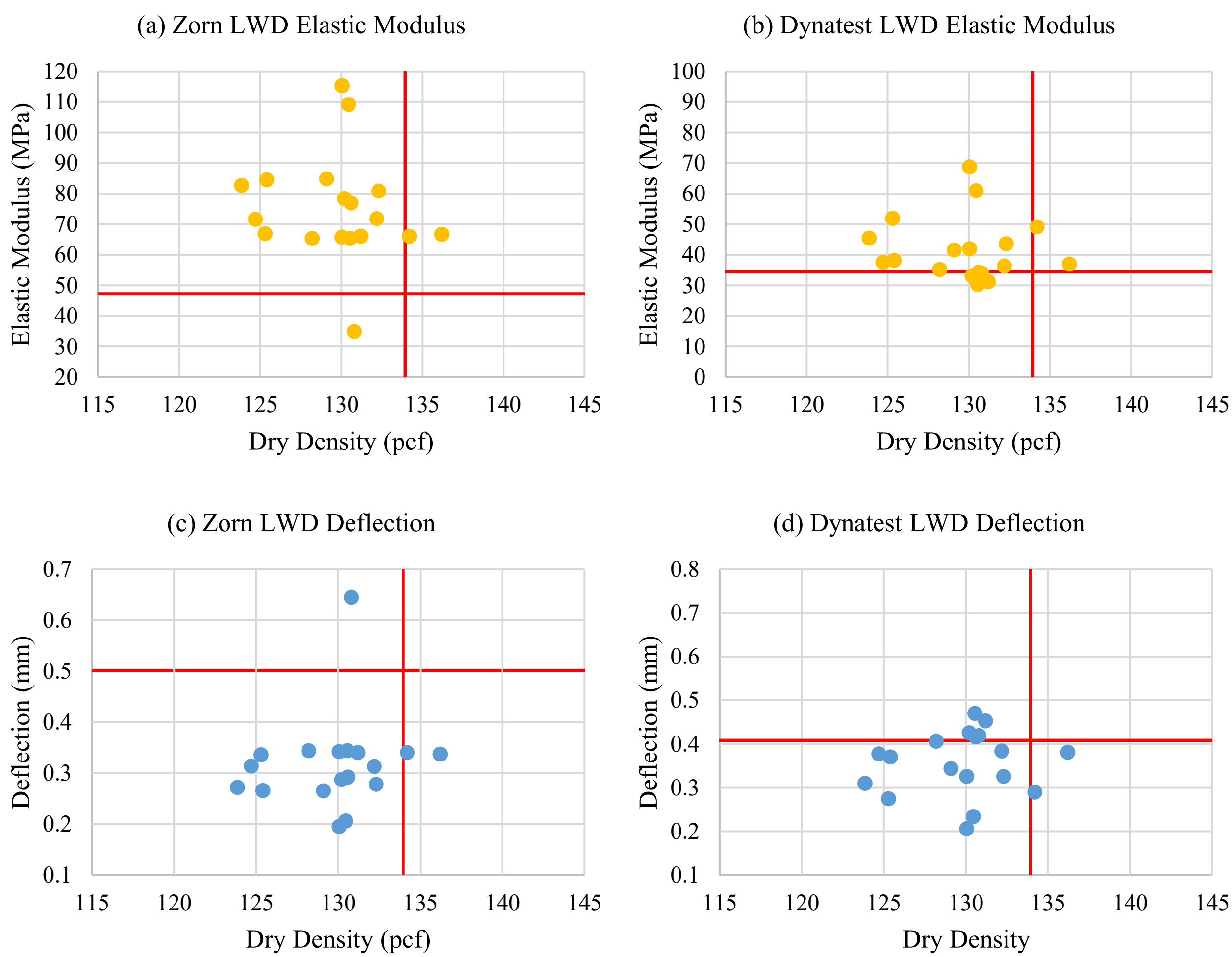
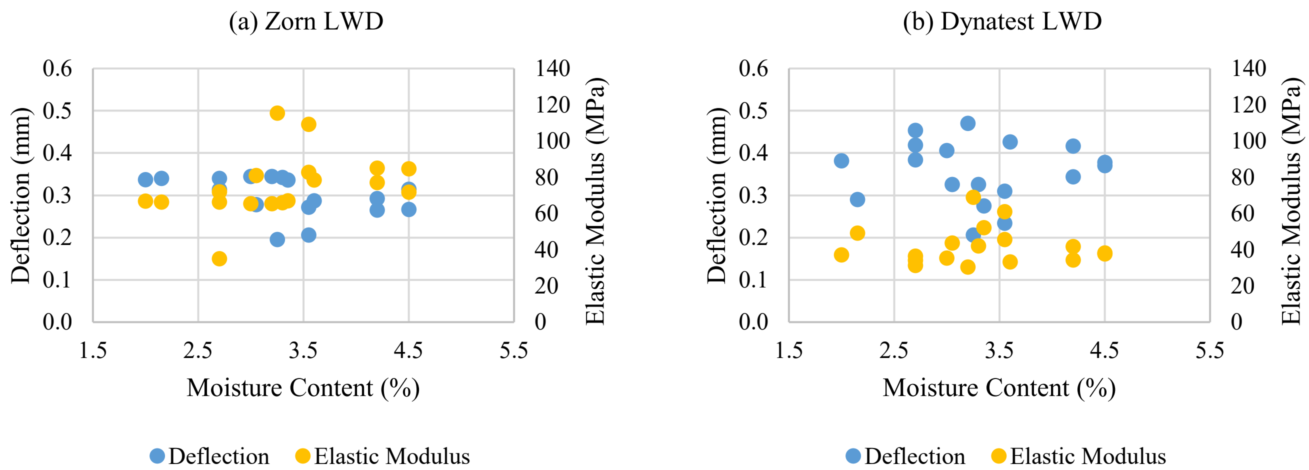


Figure 4 presents the on-grade deflection and elastic modulus values compared with the in-situ moisture content.

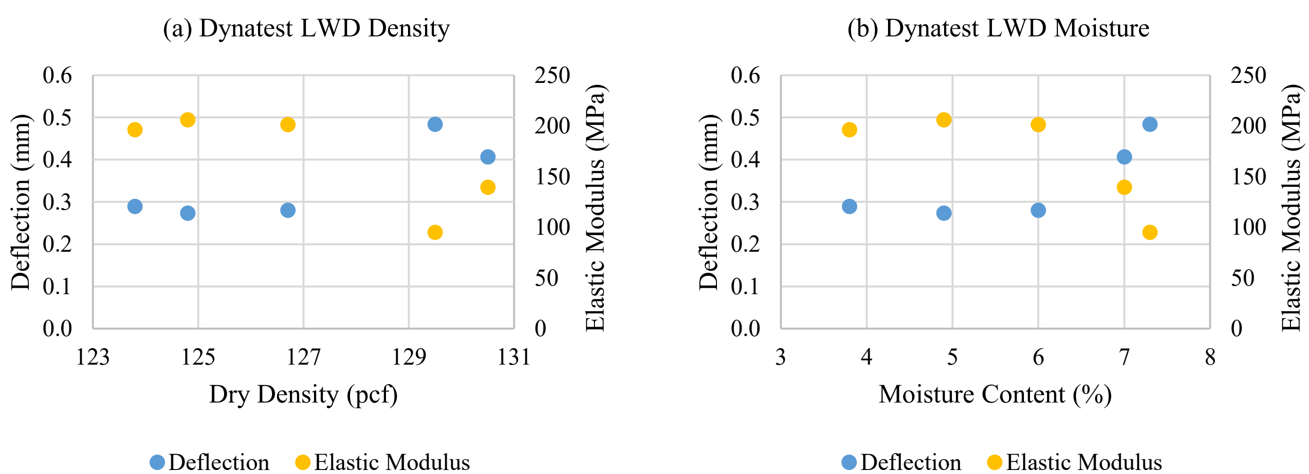
Figure 4. CABC On-Grade Testing and Moisture Content Results



Laboratory Testing

The research team conducted laboratory testing with the Dynatest LWD to establish laboratory LWD-TVs in accordance with the procedures previously discussed. Figure 5 presents the measured deflection and elastic modulus values compared with the laboratory measured dry densities and moisture contents.

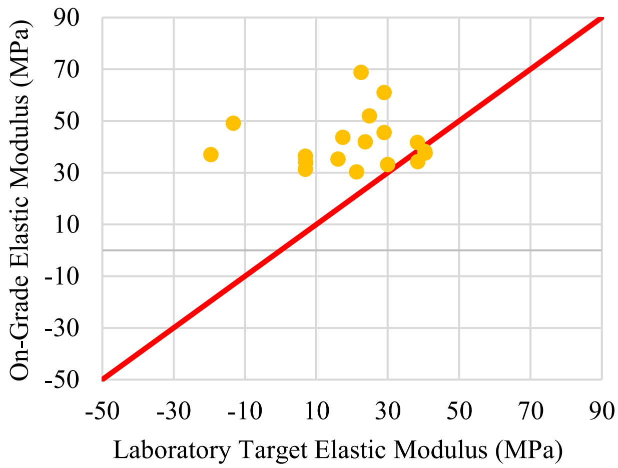
Figure 5. CABC Laboratory Testing Results



Using the laboratory procedure outlined in Chapter 2 and detailed in Appendix B the research team calculated LWD-TVs for elastic modulus of the CABC. The method does not support calculation of target values for deflection. Appendix C provides detailed calculations, the results of the multivariate regression analysis used to establish the coefficients, and a table with the LWD-TVs for each point.

Figure 6 presents the on-grade elastic modulus values compared with the LWD-TVs calculated using the laboratory method. The red line represents the 1:1 line where data points above the red line meet the acceptance criteria and data points below the red line fail to meet the acceptance criteria.

Figure 6. CABC On-Grade and Laboratory LWD-TVs



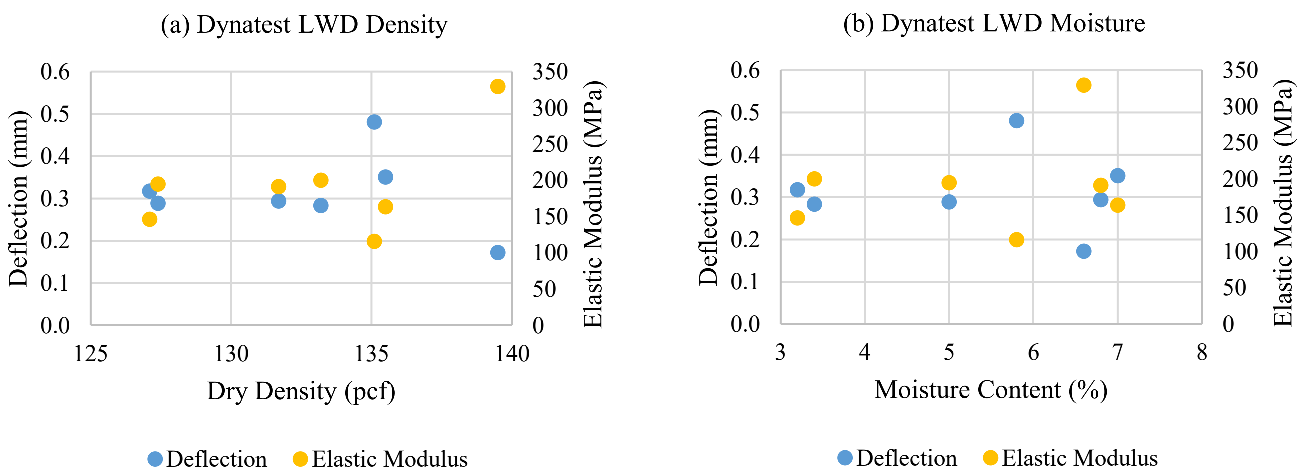
Airport Way Borrow A

The following sections present the laboratory testing and on-grade testing performed on the Airport Way Borrow A material.

<u>Laboratory Testing Data</u>

The research team conducted testing with the Dynatest LWD to determine the regression coefficients and LWD-TVs in accordance with the procedures previously discussed. Figure 7 presents the measured deflection and elastic modulus values compared with the laboratory measured dry densities and moisture contents.

Figure 7. Borrow A Laboratory Testing Results



The research team calculated target values for elastic modulus of the Borrow A. Appendix D provides detailed calculations, the results of the multivariate regression analysis used to establish the coefficients, and a table with the laboratory LWD-TVs for each point.

Figure 8 presents the on-grade elastic modulus values compared with the LWD-TVs calculated using the laboratory method.

Figure 8. Borrow A On-Grade and Laboratory Target Elastic Modulus Values

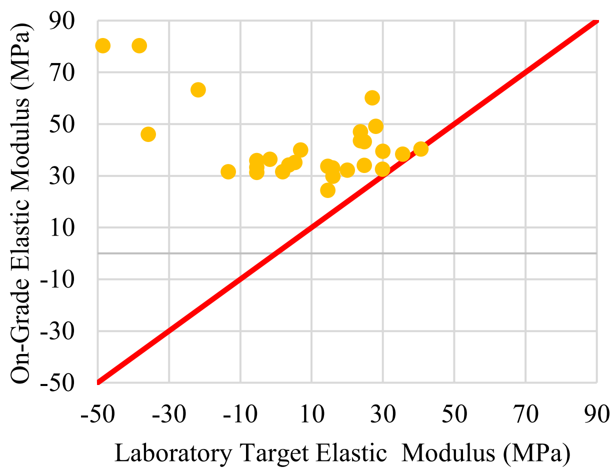


Figure 9 presents the on-grade deflection and elastic modulus values compared to the measured dry density.

Figure 9. Borrow A On-Grade Testing and Dry Density Results

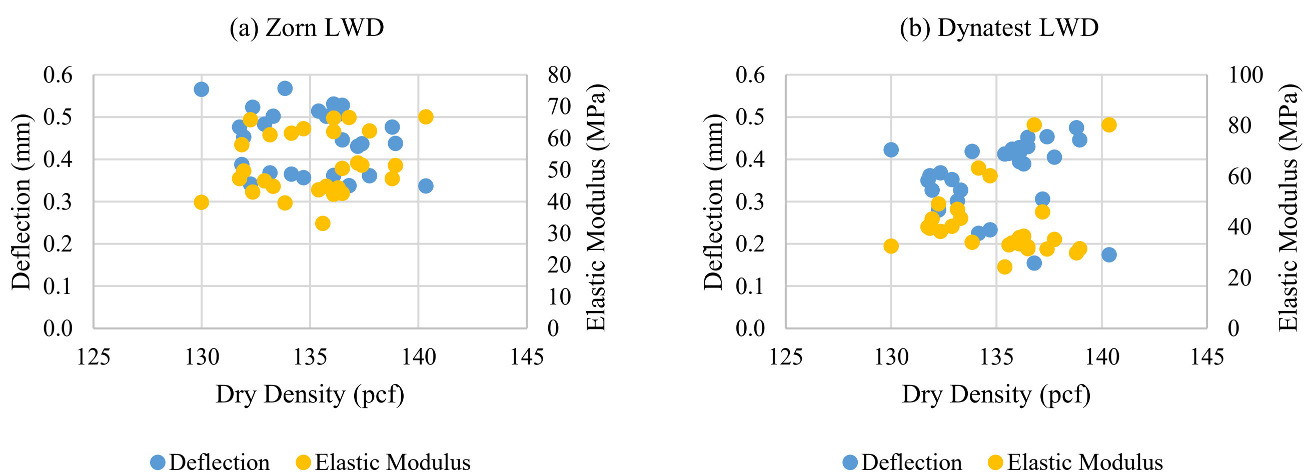
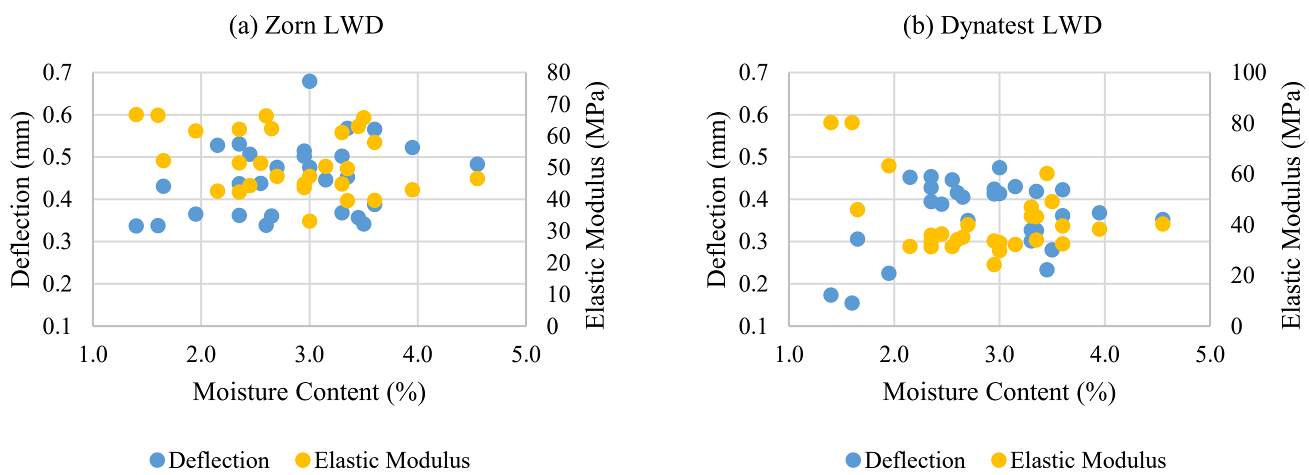


Figure 10 presents the on-grade deflection and elastic modulus values compared with the in-situ moisture content.

Figure 10. Borrow A On-Grade Testing and Moisture Content Results



Other Materials Tested

The research included testing on Airport Way Subbase F material and Ekwok CASC. The Borrow A and Subbase F gradation requirements were met by one material for the Airport Way project; however, the project team selected to discuss the materials separately as they do not have to meet the same gradation. The scope of the research did not include establishing LWD-TVs for these materials. Appendices E and F provide the results of the on-grade testing of these materials in support of developing a database of reference values for future use.

CHAPTER 4 – INTERPRETATION

Application of LWD

The findings in Chapter 3 support four main conclusions regarding the application of LWD for QA testing in Alaska:

1. The DOT&PF can use LWD testing for QA testing
2. The standard of practice in other states such as Minnesota and Indiana is applicable to Alaska
3. Acceptance can be established using elastic modulus or deflection as the target value
4. There is poor correlation between the LWD test results and moisture content within the range tested

QA Testing

The results of the testing confirm that the LWD is capable of verifying compaction and providing QA of unbound materials. As expected and shown in Figures 2a and 2b, there is poor correlation between the engineering properties measured by the LWD (modulus and deflection) and measured dry density. However, a comparison of the results from parallel LWD and nuclear moisture-density gauge tests presents patterns of passing and failing results. The upper left quadrants of Figure 3a and 3b and lower left of Figure 3c and 3d show several passing LWD tests correlated with failing density tests. These tests may indicate that current testing methods and requirements result in contractors compacting the materials more than necessary to achieve desired performance. Extra compaction is not beneficial because it increases construction costs and increases the risk of material breakdown, which increases fines content and raises frost susceptibility of the structural section.

LWD Practice

This study used the control strip test and laboratory methods to establish the LWD-TVs. The methods employed and recommended for control strip testing are comparable to the methods used by the Minnesota Department of Transportation (MNDOT) and Indiana Department of Transportation (INDOT) and adapted to be similar to ATM 309 Relative Standard Density of Soils by the Control Strip Method (ATM 309).

The proposed method (ATM 310) is comparable to the methods utilized or under development in other states. When used in combination with modifications to the Standard Specifications, ATM 310 provides a complete tool for QA testing of unbound materials that meets the standard of practice in other states, but tailored to meet the specific needs of DOT&PF.

Target Values

There is no consensus among the states currently using LWD regarding the use of deflection or elastic modulus values for the LWD-TVs. For example, MNDOT uses elastic modulus, while INDOT uses deflection.

The results did not indicate a significant difference between the collected elastic modulus and deflection values. Both engineering properties will effectively establish reliable acceptance criteria for unbound materials. The method to develop target values and apply them to construction is similar for both parameters. Other factors, including simplicity of understanding and differences in LWD device capabilities can influence the decision between elastic modulus and deflection.

Moisture Content

The relative density achieved during construction strongly depends on the moisture content of the material during compaction. Thus, it is critical to measure moisture content when using density for acceptance of unbound materials.

The data collected in this study indicate that there is not a strong correlation between moisture content and elastic modulus and deflection over the ranges evaluated. The data collected in this study was limited, but the results are consistent with other published studies. Although there were no trends or strong correlations, moisture content can provide an indication of conditions if challenges occur during construction. Therefore, the methods developed for Alaska include periodic moisture content tests to inform construction activities.

Value of LWD Use & Research

The DOT&PF can use information from this research to guide future studies and implementation of the LWD methods. Utilizing LWD has the potential to increase savings, enhance safety, simplify project logistics, and improve overall product quality.

The DOT&PF estimates annual spending on nuclear moisture-density gauges totals over $250,000 in addition to the costs accrued by consultants and contractors acting on DOT&PF's behalf. This cost includes annual NRC license cost, radiation safety requirements, hazardous material certifications, training for technicians, calibration and operation expenses, transportation to remote communities, and secure storage facilities. LWD devices eliminate all expenses related to hazardous material requirements, minimize transportation costs, and reduce the calibration and operation expenses required for QA devices.

The DOT&PF prioritizes employee safety as the top concern on all construction sites. Nuclear moisture-density gauges, despite being generally safe when operated and tended by a trained technician, pose inherent dangers due to the presence of radioactive material in the device. By removing nuclear-based devices, the DOT&PF can immediately increase safety for technicians, contractors, consultants, and other individuals present during acceptance testing on a construction site.

LWD devices are especially well suited for work in remote Alaska due to their ease of transportation compared to nuclear moisture-density gauges, which are classified as hazardous materials and thus have many restrictions when shipped to remote Alaska. Passenger flights cannot transport nuclear moisture-density gauges, limiting the transportation options for remote villages since cargo and passenger planes are often the same. Often, a nuclear moisture-density gauge requires a charter flight from a hub community such as Bethel, Anchorage, Fairbanks, or Kotzebue to the project site in more remote villages. Since they have no hazardous components, LWDs are safe to check as personal baggage on all major airlines and carry onto small commuter flights from hub communities to remote villages. The ease of transportation and logistics is a major advantage offered by LWD testing methods in Alaska.

Unlike statically determined maximum dry density, elastic modulus and deflection are dynamically determined proxy values with good correlation to engineering parameters like resilient modulus used to design DOT&PF projects in Alaska. Other research shows modulus and deflection provide better correlation to roadway performance, and the DOT&PF will see increased product quality over time with LWD use.

Resources for LWD Implementation

This study included development of preliminary field and laboratory testing methods. Refinement and revision of the preliminary field methods resulted in ATM 310 to determine the LWD-TV using a control strip. Appendix B contains additional information regarding ATM 310 and the preliminary laboratory method. Due to complexities encountered during this study, the research team deemed the laboratory method impractical and was not refined further.

This study included proposed modifications to the Standard Specifications to incorporate LWD testing as an alternative to density testing for QA. The Standard Specifications are written to allow the use of LWD or nuclear moisture-density gauge for acceptance as the DOT&PF transitions to the preferred methodology. Appendix B provides the proposed modifications to Sections 203, 205, 301, and 308 of the Standard Specifications.

Appendix G includes LWD reporting forms for use during control strip and on-grade acceptance testing.

We developed materials to help the DOT&PF train its employees in support LWD implementation. The research resulted in two types of training materials: an LWD checklist, which technicians can carry as a refresher or include in each LWD case for reference, and a slideshow presentation for use in classroom training situations. The slideshow presentation's intended audience is DOT&PF technicians who are new to LWD usage and testing methods. Appendix H contains the training materials.

Limitations

Although the scope was limited, this research provides a critical step in implementing LWD methods for acceptance testing in Alaska. The research identifies the main limitations of LWD use to be lack of a statewide LWD-TV database, bonded materials, correlations required to estimate design parameters, and cumbersome laboratory methods.

The original scope of the study included testing on the Airport Way project on a limited number of materials. The research did not include all potential unbound materials used throughout Alaska, and the limited data could not establish a correlation or trend between moisture content and the LWD parameters. Further research could evaluate the presence or absence of a correlation between moisture content and LWD values.

Currently, LWD testing is only feasible for QA testing of unbound materials. Other QA testing methods, such as laboratory testing of asphalt cores, will still be required for bound materials like asphalt-treated bases and hot mix asphalt.

MNDOT and IDOT have adequate number of tests on their typical construction materials to support the use of empirically based target values. The scope of this research did not include sufficient number of tests to generate empirically based target values.

As described in the Alaska Flexible Pavement Design Manual, the DOT&PF uses resilient modulus values to design pavement structural sections. LWD devices do not directly measure resilient modulus values. As a result, we are still limited to proxy values when correlating QA values with design values. LWD devices use a known dynamic load to create a measureable deflection. Elastic modulus is calculated from dynamic load and measured LWD deflection. Resilient modulus correlates well with the LWD proxy value of elastic modulus.

This study found that the laboratory testing method for determining LWD-TVs is currently not feasible for implementation in Alaska due to its cumbersome nature and the significant mathematical calculation that it requires. However, as the laboratory methods are refined in other states, this method may become more viable for determining LWD-TVs in the future.

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

Several states use LWDs rather than nuclear moisture-density gauges for QA. LWD testing methods offer several key advantages in Alaska over density testing. The key advantages include:

- Easier transportation logistics
- Lower cost to DOT&PF, consultants, and contractors
- Better correlation between QA values and intelligent compaction techniques
- Better long-term performance

This study confirmed that LWD testing works well for the Alaskan soils tested and will have broad application for materials across the state.

LWD Implementation

The team developed the following conclusions and recommendations from the research.

Database Creation

We recommend that DOT&PF create a database to record and document the LWD-TVs and on-grade test values for the various materials used for construction across Alaska. The database should include entries such as material source (MS) name, MS number, MS location, project location, material type, engineering properties, compaction equipment used, LWD device information, and LWD-TVs. The database will support development of empirical LWD-TVs and make use of LWD testing even easier in the future.

Laboratory Determination of the LWD-TV

The laboratory method for determining LWD-TVs is not a viable method for Alaska at this time. This method requires significant mathematical calculations, including a multivariate regression analysis, to determine acceptance of a material. Negative modulus values are not possible in reality; however, several of the laboratory determined LWD-TVs in this study were negative. The project team recommends that DOT&PF does not pursue the laboratory method further at this time. DOT&PF could consider revisiting this method if the laboratory method is refined through other research.

Control Strip Determination of the LWD-TV

We recommend that DOT&PF implement the control strip method for determining LWD-TVs. The control strip method is simple, easy to implement, and is similar to existing test methods such as ATM 309. Additionally, it allows for on-site determination of LWD-TVs.

Deflection Target Values

LWD devices are capable of measuring and/or calculating elastic modulus and deflection values, and either is applicable for acceptance testing. Based on discussions during this study, DOT&PF selected deflection as their target value. Deflection is an easier concept to understand and communicate, which will increase technicians' efficiency in interpreting and discussing results with contractors. Furthermore, all LWD devices currently on the market can directly measure deflection, whereas modulus is an approximated value for some devices.

LWD Device Characteristics

DOT&PF should evaluate all LWD devices on the market before selecting a preferred device. We recommend that DOT&PF prioritize and evaluate robustness, ease of use, device setup, ASTM Standards, calibration requirements, maintenance requirements, and manufacturing locations. The following list describes some of the criteria to evaluate when selecting an LWD device:

Criteria 1: Prioritize the robustness of the LWD device, including any computer or software components. The entire LWD setup needs to be able to operate in Alaska's extreme weather conditions and withstand frequent travel and shipping.

Criteria 2: Construction demands require efficient and easy LWD testing. Ease of use will also decrease training requirements and user error.

Criteria 3: Deflection and modulus values depend upon several device setup properties, including drop height, drop weight, and plate size. If DOT&PF decides to utilize multiple LWD devices, standardization between these properties will be essential for consistent LWD implementation.

Criteria 4: Currently marketed LWD devices fit under one of two ASTM standards, ASTM E2583 Standard Test Method for Measuring Deflections with a Lightweight Deflectometer or ASTM 2835 Standard Test Method for Measuring Deflections using a Portable Impulse Plate Load Test Device. Evaluate which ASTM standard better fits the needs of DOT&PF.

Criteria 5: Consider the manufacturer calibration requirements, including the frequency and the calibration process.

Criteria 6: Consider the required routine maintenance and the shipping location for LWD repairs.

Criteria 7: Consider manufacturing locations or distributors for ease of ordering new LWDs.

Suggested Additional Work

The research team recommends the DOT&PF identify a project to use LWD testing for QA. The project will help DOT&PF learn to use LWDs, communicate with contractors on the performance of materials based on LWD testing, and identify nuances that apply to LWD use in Alaska. Additional work could also incorporate testing on additional material types or testing this method on airport construction.

In addition, we recommend DOT&PF identify follow-up projects in each region to provide opportunities to incorporate LWD testing throughout the state. Projects in remote Alaska that do not include asphalt testing are particularly well suited to highlight the advantages of LWD testing.

REFERENCES

AASHTO, “Compaction Quality Control Using Light Weight Deflectmeter (LWD)” *AASHTO* (2017) pg 122 to 129

AASHTO, “Draft Laboratory Determination of Target Modulus using Light Weight Deflectometer (LWD) Drops on Compacted Proctor Mold” *AASHTO* (2017) pg 115 to 121

ASTM, “E2583 Standard Test Method for Measuring Delections with a Light Weight Deflectometer” *American Society for Test Methods* Vol 04.03 (2022) pg 1564 to 1566

ASTM, “E2835 Standard Test Method for Measuring Delections using a Portable Impulse Plate Load Test Device” *American Society for Test Methods* Vol 04.03 (2022) pg 1692 to 1696

Indiana DOT, “203.24 Method of Making Strength, Stiffness and Density Tests” *Indiana DOT* (May 2019) pg 175 to 178

Indiana DOT, “218-R-576 QA/QC for Soil Fill Sections and QC-QA for Subgrade” *Indiana DOT* (September 2021) pg 1 to 3

Khosravifar, Sadaf, “Large-Scale Controlled-Condition Experiment to Evaluate Light Weight Deflectomenters for Modulus Determination and Compaction Quality Assurance of Unbound Pavement Materials” PhD dissertation, University of Maryland (2015) pgs 388

Minnesota DOT, “5-692.256 Light Weight Deflectometer – LWD Procedure & Target Value Determination from the Minnesota Grading and Base Manual” *Minnesota DOT* (June 2019) pg 77 to 82

Minnesota DOT Geotechnical Section, “MnDOT Spec 2106.3F” *Minnesota DOT* (June 2019) pg 1

Nazarian, Soheil, Mazari, Mehran, Abdallah, Imad, Puppala, Anand, Mohammad, Louay, & Abu-Farsakh, Murad, “NCHRP 10-84 Modulus-Based Construction Specification for Compaction of Earthwork and Unbound Aggregate” *National Cooperative Highway Research Program* (August 2014) pg 1 to 184

Nebraska DOT, “NDR T 2835 Deflection Measurement of Soils using a Lightweight Deflectometer (LWD)” *Nebraska DOT* (2014) pg 1 to 5

Ingios Geotechnics, Inc, “Demonstration of Innovative Technologies for Pavement Foundation Layer Construction: Iowa DOT Open House” *Iowa DOT* (January 2023) pg 1 to 68

Appendix A – Literature Review

Literature Review Summary

Minnesota DOT LWD Method 5-692.256 from the Minnesota DOT Grading & Base Manual

Minnesota DOT Spec 2106.3F

Indiana Test Method 508

Indiana DOT LWD Spec 203.24

Indiana DOT Spec 218-R-576

Nebraska DOT LWD Test Method T 2835

ASTM E2583

ASTM E2835

Draft AASHTO Spec TP 123-01 and TP 456-01

Literature Review Summary

HDL conducted a literature review of the existing LWD related specifications, test resources, and research studies. As part of our initial literature review, we met with representatives from the Indiana and Minnesota Departments of Transportation (DOT). The following sections summarize the literature that most informed our research process. Appendix A also includes copies of referenced materials that are not readily available on line.

Minnesota DOT

MNDOT's current procedure uses the Zorn LWD and elastic modulus as their target value. Minnesota utilizes two approaches for establishing the LWD target values for QA testing. Minnesota determines the target values using a calibration area (control strip) or predetermined target values for specific materials. MNDOT's procedure allows for LWD use with granular soils, aggregates, and reclamation. The calibration area method that Minnesota uses is similar to the method recommended for Alaska; however, ATM 310 recommends deflection as the target value instead of elastic modulus. Table A1 summarizes the calibration area requirements utilized by Minnesota.

Table A1. Minnesota DOT LWD Calibration Area Requirements

<table>
<tr><th colspan="4">LWD Calibration Area Dimensions (Note 1)</th></tr>
<tr><th>Embankment</th><th>Length</th><th>Width</th><th>Fill Thickness</th></tr>
<tr><td>Roadbed Embankment Soil, Reclamation, and Base</td><td>≥ 50 feet</td><td rowspan="2">Equal to the excavated embankment width</td><td rowspan="2">Equal to the planned layer thickness for base or reclamation & 12-inch minimum for embankment</td></tr>
<tr><td>Miscellaneous trench, culvert, or other tapered construction</td><td>≥ 10 feet</td></tr>
</table>

Note 1: Or as determined by the Engineer.

Minnesota has used LWDs for QA for many years and has developed a set of predetermined target values for some common materials. Table A2 provides an example of the predetermined target values.

Table A2. MNDOT LWD Predetermined Target Values

LWD Minimum Elastic Moduli for Granular, Clay and Clay Loam, and Base		
Specification	**Material Type**	**Minimum Elastic Modulus [MPa]**
2106	Granular	40
	Clay and Clay Loam	20
2211 or 2215	Base or Reclamation	50

Appendix A includes a copy of the full Minnesota procedure.

Indiana DOT

INDOT uses LWD's similar to the MNDOT, including target value determination using calibration areas or predetermined values for specific materials. However, Indiana uses deflection as their target value, not elastic modulus. Indiana's specification allows for LWD use with granular soils, aggregates, and chemically modified soils. The Indiana DOT utilizes Indiana Test Method (ITM) 508 as the guidance document for field determination of deflection with LWDs. Appendix A includes a copy of ITM 508, Indiana Standard Specification 203.24, and Indiana Special Provision 218-R-576.

Nebraska DOT

The Nebraska Department of Transportation (NDOT) utilizes LWD methods similar to those of MNDOT and INDOT. The NDOT Standard Test Method T2835 describes Nebraska's LWD test methodology. Deflection is the target value utilized in Nebraska. NDOT does not currently include LWD in their Standard Specifications or Special Provisions. Appendix A includes a copy of the NDOT Standard Test Method T2835.

ASTM E2583/ E2835

ASTM E2583, Method for Measuring Deflections with a Lightweight Deflectometer, and ASTM E2835, Method for Measuring Deflections using a Portable Impulse Load Test Device, provide standards for measuring deflections with LWD devices. Devices meeting the requirements of ASTM E2583 have a load cell while devices that meet ASTM E2835 do not have a load cell. Indiana DOT, Minnesota DOT, and academic research teams follow the same general procedure as outlined in both ASTMs. Of the LWD devices that are commercially available, the Dynatest model meets ASTM E2583, while the Zorn and Olson models meet ASTM E2835.

NCHRP10-84

The researchers aimed to propose a specification for modulus-based field-testing using LWD in the NCHRP10-84 study. They identified that the existing methods for modulus-based field-testing did not provide a correlation between the measured field modulus values and the target values. At the time of publication in 2014, the study notes that most states used nuclear density gauges as the standard of practice, and only two states indicated the use of modulus-based devices. The study identified that quality construction that meets modulus requirements correlates poorly to density. Additionally, the study defined a process for relating field moduli and target moduli, a previously identified gap in the practicality of modulus-based specifications. Appendix A does not include this study, as it is publically available.

Academic Studies

Sadaf Khosravifar, PhD conducted a dissertation that assessed LWD's potential for use in quality assurance through a large-scale controlled experiment to establish a technique for standardizing LWD's determination of modulus for unbound pavement materials. The study used field and laboratory techniques to determine the LWD target values, with the laboratory method being of particular interest. Although it is logistically easy to add LWD testing to proctor testing in the laboratory, the calculations required to convert the measured LWD values from the proctor test into a comparable LWD-TV for field-testing are more complicated than is practical.

Minnesota DOT Grading & Base Manual Section 5-692.256 Lightweight Deflectometer – LWD Procedure & Target Value Determination

5. Have 3 locations/roller pass spaced out a minimum of 20 feet for embankment or 2 locations/roller pass spaced out a minimum 6 feet minimum for trenches.
6. For each additional rolling pass, space testing locations at least 1 foot from the prior test location.
7. Continue roller passes and testing to determine the minimum penetration index value.
8. Penetration value should be within 5 mm of each other.
9. When minimum penetration values are reached, average these measurements, for the three embankment locations or two locations for a trench. The DCP-Target Value is the average plus 2 mm.
10. DCP-Compaction compliance: Compaction compliance is achieved when each Penetration Index is no greater than the DCP-Target Value.
11. Document on the DCP form that an alternate DCP-Target value was used based upon a calibration area.

5-692.256 Light Weight Deflectometer – LWD Procedure & Target Value Determination

Part 1 – LWD Procedure for Zorn ZFG2000, 3000, and Small/Lab Model

A. Summary of Test Method

1. This test method is a plate-bearing test. The load is generated by a falling mass dropped onto a plate that transmits the load pulse on the tested material.
2. The weight is raised to a preset height that when dropped imparts a force pulse, and the vertical deflection is measured.
3. The peak deflection resulting from the force pulse at each location is recorded.
4. The drop height of the falling weight is fixed and not changeable by the user.
5. If another device is used, follow the manufacturer's operating manual.

B. Equipment

The Zorn LWD is comprised of the following elements (see Figure 27).

1. *"Handle Grip"* is located at the top of the device. It is used to hold the LWD guide rod plumb and to limit the upward movement of the falling weight.
2. *"Top Fix and Release Mechanism"* holds the falling weight at a constant height. The release mechanism is depressed to allow the falling weight to freely drop and transmit the load pulse through the plate resting on the tested material.
3. *"Guide Rod"* allows the falling weight to drop freely the set distance of about 20 inches. The guide rod and the falling weight together weigh about 33 pounds.
4. *"Falling Weight Grip"* provides a grip for the operator to raise the falling weight to the top fix and release mechanism.
5. *"10-kg Falling Weight"* is manually raised to the bottom of the grip and held in place using the top fix / release mechanism. Note: 5-kg for Zorn Lab Model.
6. *"Lock Pin"* has two positions (locked and unlocked). Pull the pin to release the falling weight for measurements.

7. *“Steel Spring”* provides the buffer system that transmits the load pulse to the plate resting on the material to be tested.
8. *“Anti-Tipping Fixture”* prevents the guide rod and falling weight from tipping when these parts are placed, and standing freely, on the load center ball / loading plate.
9. *“Load Center Ball”* serves as a connector between the anti-tipping fixture and the loading plate. It also allows for disassembly, which reduces the size of the instrument for transport.
10. *“Carry Grip”* provides handles to assist the operator with carrying the loading plate.
11. *“Loading Plate”* provides an approximate uniform distribution of the impulse load to the surface. The loading plate weighs about 33 pounds, but less for lab model.
12. *“Cable”* is used to connect the loading plate sensor to the data processing and storage system.

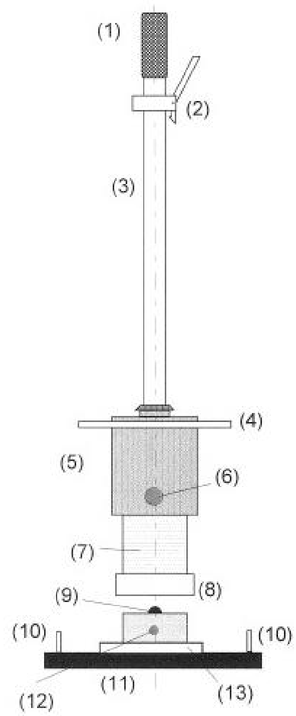


Figure 27 Schematic Drawing of Light Weight Deflectometer.

Data Processing and Storage System (see Figure 28):

Deflection data is displayed and recorded on the data processing and storage system. Smaller handheld data processing and storage devices are now available.

Figure 28 Sketch of electronic LWD output device.

C. LWD Configuration

The standard LWD configuration is as follows:

- Falling Weight: 10 kg, 5 kg for Zorn lab model
- Load Plate Diameter: 200 mm, 150 mm for Zorn Lab model
- Drop Height: See calibration plate connected to the LWD device.

D. Testing Constraints

1. Perform test after compaction.
2. Test when the air temperature is from 36 to 120 degrees Fahrenheit.
3. Ensure soil is not frozen.

E. Site Selection and Preparation

1. Visually inspect the percentage of gravel in the soil. Ensure the percentage of gravel, larger than 1”, is less than 25 percent.
2. Create a relatively smooth and level spot that will allow the LWD guide rod to remain vertical and prevent sliding of the loading plate during testing.
3. Select the most yielding area.
4. Prepare a test area that is at least 1.5 times wider than the diameter of the plate, i.e. 1 square foot.
5. Remove loose, dried, cracked, or uneven material prior to testing.
6. Perform tests at a uniform depth, representative of the compaction state. Ensure consistent test depths are used, for each target value determined from Part 2 of this section.
7. The influence depth is approximately 1 to 1.5 times the plate diameter; consequently, deflection measurements obtained for lifts less than this depth are a composite deflection measurement.

F. Procedure

1. Position loading plate on test site.

2. Turn loading plate left and right 45 degrees.
3. Perform six falling weight load pulses and use the following procedure for each load pulse:
   a. Raise falling weight to calibration height (preset drop height).
   b. Snap falling weight into fix and release mechanism.
   c. Adjust guide rod to vertical.
   d. Release falling weight and allow it to freely fall.
   e. Catch falling weight after rebound.
   f. Snap weight into fix and release mechanism after rebound.
4. Record resulting resilient modulus results.
5. Record supporting information such as location measurements and identification data.
6. Repeat deflection measurements at another location (move at least two feet longitudinally) when either of the following or similar occurs:
   a. Mis-catch of falling weight after rebound occurs.
   b. The load plate slides.
7. Obtain the moisture content on a sample collected 3 to 9 inches below LWD test depth surface using a test method in the Grading and Base (Pavement Foundation) Manual. Record the moisture content information on the LWD form.
8. The first three drops are for "seating" and the next three drops for analysis.
9. Make sure the falling weight falls from the top height.
10. Ensure the following for LWD equipment constructed using a centering ball: (1) the guide rod is not removed from the centering ball and (2) the load plate is not displaced during testing.
11. When performing LWD tests on subgrade material, remove at least 4" of material, if the top surface has dried and is crusted over. This occurs most often with clay subgrades that have dried for two hours or more.

G. Safety

1. Keep back straight and lift with leg muscles to help prevent injury when elevating and dropping the falling weight.
2. Make sure hands or extremities are not positioned beneath the lifted, falling weight or loading plate to avoid injury.
3. Secure falling weight into the lower position prior to transport to prevent injury from movement of the falling weight.

H. Maintenance and Handling

1. Inspect equipment for necessary repairs.
2. Store LWD in case in a dry place when not in use.
3. Make sure guide rod is not directly resting on soils.

4. Clean the loading device by removing any dirt with a dry cloth. Do not grease/oil the guide rod.
5. Check the drop height regularly to ensure that slippage of the release mechanism has not occurred.
6. For devices with rechargeable batteries: Recharge batteries after 3 to 12 hours of use or on 3-month intervals when not in use. Charge or replace the battery when the charging level is less than 50 percent.
7. The hand-held units use disposable AA batteries, so have an extra set available, and remove them after construction is complete.
8. Ensure rubber bellow is providing a tight seal around the spring.

I. Calibration

Calibrate the force generation device and the deflection sensor once per year per ASTM E 2835. *Have copy of Calibration Certificate available for the Independent Assurance Inspector. For units that have not been used or used very little, you may extend the calibration occurrence to two years.*

Part 2 Light Weight Deflectometer (LWD) Target Value Determination

A Definitions

"Deflection Test Measurement" is the average deflection measured from the fourth, fifth and sixth drop in the testing sequence. The first, second and third drop in the testing sequence are seating drops.

"LWD-TV" is the LWD Target Value determined using a calibration area for a given soil type or source.

B LWD Testing Constraints

The LWD Deflection Method cannot be used when:

1. Embankment thicknesses are less than 1 foot, or
2. Base or reclamation thicknesses are less than 4 inches, or
3. When testing within 3 feet of the water table.

C Determine the LWD-TV using a Calibration Area

1. Calibration Area Requirements

Construct the Calibration area to determine the LWD-TV for each type or source of materials.

2. Construct a new Calibration Area when:
   a. There is a new source, or an observable variation in material properties or a Proctor is required,
   b. the moisture content of the material varies more than 2 percent of the calibration area moisture content, or
   c. as determined by the Engineer.

3. Calibration Area Dimensions, see Table 15 below.

Table 15
LWD Calibration Area Dimensions (Note 1)

Embankment	Length	Width (ft)	Fill Thickness
Roadbed Embankment Soil, reclamation, and Base	≥ 50 feet	Equal to the excavated embankment width	Equal to the planned layer thickness for base or reclamation & 12 inch minimum for embankment
Miscellaneous trench, culvert, or other tapered construction	≥ 10 feet	Equal to the excavated embankment width	Equal to the planned layer thickness for base or reclamation & 12 inch minimum for embankment

Note 1: or as determined by the Engineer.

4. Moisture Requirements
   a. Determine the Target Moisture Content by one of the following:
      i. Standard Proctor
      ii. 1-Point Proctor
      iii. Estimated Optimum Moisture Content Form G&B-305 (for Granular or base only)
   b. The moisture content must be from 65 to 102 percent of the Target Moisture Content for embankment material and as required in 2211 for base or 2215 for reclamation.
5. Save a material sample from each calibration area for comparison to the embankment material being compacted.
6. Calibration Area construction is incidental to the embankment compaction requirements.
7. Space out calibration test locations a minimum of 20 feet apart for base, reclamation, and embankment and 6 feet minimum for trenches.
8. For each additional rolling pass, space testing locations at least 2 feet from a prior test.
9. Start test curve determination at least two passes before you think maximum compaction will be achieved.
10. For roadbed embankment soil, reclamation, and base have three tests locations/roller pass
11. For trench, culvert or other tapered construction have two Tests locations/roller Pass
12. Forms are available on the Grading & Base website.
13. Continue roller passes and testing to determine the minimum deflection value.
14. Calibration Area Construction

a. Begin LWD testing on the test layer at least two passes before you believe you will reach the desired compaction. Start test curve determination will be achieved.

b. LWD-TV Compaction is obtained when:

   i. The moisture content is within the required range.

   ii. The average of the resilient moduli measurements, for three consecutive passes, does not significantly change with additional compaction. The LWD-TV is the highest average resilient modulus from these passes.

15. LWD-Compaction compliance

a. Compaction Compliance Requirement

   Compaction of the material is achieved when each Deflection Test Measurement is ≥0.80∗LWD-TV.

b. Obtain new LWD-TV when:

   i. More than 20 percent of the Deflection Test Measurements are ≤ 0.80∗LWD-TV, or

   ii. Failing results consistently occur and adequate compaction is observed through quality compaction.

Testing Rate

Follow Schedule of Materials Control.

Part 3 Light Weight Deflectometer (LWD) Predetermined Target Method

In lieu of using the Target Value method in Part 2, the Engineer can use the Predetermined Target Method per the following:

Compact the entire lift to achieve the LWD-TV per Table 16. If quality compaction is not achieved while meeting the minimum elastic modulus, raise the minimum elastic modulus.

The Engineer may also use both the target value method in part 2 and the predetermined target method in part 3 to determine target values.

Use Form G&B-604.

Table 16 LWD Minimum Elastic Moduli for Different Materials
LWD Minimum Elastic Moduli for Granular, Clay and Clay Loam, and Base

Specification	Material Type	Minimum Elastic Modulus [MPa]
2106	Granular	40
2106	Clay and Clay Loam	20
2211 or 2215	Base or Reclamation	50

5-692.260 Pulverization Determination for Binder Soils

A. Scope

This test method covers a procedure for the field determination of the degree of pulverization of binder soils.

Minnesota DOT Standard Specifications for Highway Construction 2020, Section 2106 Excavation and Embankment – Compacted Volume Method

The Department will pay for removing pavement and miscellaneous Structures on the basis of the following schedule:

Item No.	Item	Unit
2104.501	Remove*	lump sum
2104.502	Abandon*	each
2104.502	Remove*	each
2104.502	Salvage*	each
2104.503	Remove*	linear foot
2104.503	Salvage*	linear foot
2104.503	Sawing Bituminous Pavement	linear foot
2104.503	Sawing Concrete Pavement	linear foot
2104.504	Remove*	square yard
2104.507	Remove*	cubic yard
2104.518	Remove*	square foot

* Specify item name, such as: Culvert pipe, sewer pipe, drain pipe, curb and gutter, curb, Sidewalk, fence, concrete or masonry Structures, railroad track, manholes or catch basins, integrant curb, concrete pavement, bituminous pavement, pavement, trench pavement, guardrail, water well, etc.

2106 EXCAVATION AND EMBANKMENT – COMPACTED VOLUME METHOD

2106.1 DESCRIPTION

This Work consists of excavating, placing, compacting, testing, finishing, and disposing of embankment Materials.

Materials are classified as either excavation or embankment Materials.

No shrinkage or swell factors have been applied or will be applied to any Excavation or Embankment items.

2106.2 MATERIALS

A Excavation

A.1 Excavation – Common

Material not classified in any other category. Excavation-common includes topsoil excavation.

A.2 Excavation – Subgrade

Material in the Road Core below the Grading Grade exclusive of Excavation – rock, Excavation – muck, Excavation – channel and pond, Excavation – rock channel.

A.3 Excavation – Rock

Material that requires drilling, blasting, or ripping before excavation. This includes boulders and other detached rock larger than 1 cubic yard.

A.4 Excavation – Muck

Organic Soils and other unstable soils, and below the natural ground level of marshes, swamps, or bogs, regardless of the moisture content. Muck excavation is limited to areas over which the Roadway embankment or a Structure is to be constructed.

A.5 Excavation – Channel and Pond

Material from channel changes, waterways, and ponds outside of the Roadway embankment not classified as rock channel excavation.

A.6 Excavation – Rock Channel

Material classified as rock excavation from channel changes and waterways outside of the Roadway embankment.

B Embankment

B.1 Common Embankment

Select Grading Material, mineral soils found in the Triaxial Chart in the *Grading and Base Manual*, excluding Silt. Organic Soils and Marl are also excluded.

Select Grading Material may contain up to 100 percent recycled Materials composed of recycled concrete (maximum of 75 percent), and recycled asphalt.

B.2 Granular Embankment.. 3149.2B

Table 3149.2-1, Granular Material

B.3 Select Granular Embankment 3149.2B

Table 3149.2-1, Select Granular Material

B.4 Select Granular Embankment Super Sand.. 3149.2B

Table 3149.2-1, Select Granular Material (Super Sand)

B.5 Select Granular Embankment Modified 10 percent 3149.2B

Table 3149.2-1, Select Granular Material Modified 10 percent

B.6 Stabilizing Aggregate 3149.2C

B.7 Topsoil

Topsoil is the existing Material within the construction limits that is suitable for plant growth and that originates from the A and/or B horizon soils. Peat and other Organic Soils may be used to supplement the existing topsoil, if approved by the Engineer. Topsoil is included as a portion of the total common embankment outside of the Road Core.

B.8 Non-structural Embankment

Mineral soils, excess topsoil, and Organic Soils capable of supporting construction Equipment. Non-structural embankment is included as a portion of the total common embankment outside of the Road Core.

2106.3 CONSTRUCTION REQUIREMENTS

A General

Before beginning excavation and embankment operations, comply with the requirements of 2101, “Clearing and Grubbing.”

Comply with the erodible surface requirements of 2574, “Soil Preparation.”

Strip, stockpile and reuse in-place topsoil in areas to be disturbed by construction.

For Road Core embankment, below granular or base Layers, use Material meeting the requirements of 2106.2B.1, “Common Embankment.”

Non-structural grading Materials may be used as embankment outside the Road Core.

Perform excavation and embankment operations within the Plan excavation limits as required by the Contract.

Maintain drainage in excavations and embankment operations. Provide and maintain temporary drainage facilities until the permanent facilities are complete and operational.

Do not leave undrainable depressions.

Provide and maintain temporary preparation and erosion control on embankment and stockpiles until finishing operations per 2106.3I, “Finishing Operations,” are complete.

Repair or replace settlement plates damaged by Contractor operations or negligence.

Protect Structures during construction operations. Repair Structures damaged by Contractor operations.

Excavated Material from within the Project limits shown on the Plans that meet Project requirements and complies with 1405, “Use of Materials Found on the Project,” may be used for embankment Material.

Place stabilizing Aggregate in accordance with 2211, “Aggregate Base.”

Forms and the *Grading and Base Manual* are available on the Department Grading and Base Website.

B Contractor Quality Control (QC) Testing and Aggregate Certification

Test according to the *Schedule of Materials Control*.

Certify Materials on Form G&B-104.

Material placed without certifications is unauthorized Work in accordance with 1512, “Unacceptable and Unauthorized Work.”

C Moisture Control

Meet the moisture content requirements during compaction listed in Table 2106.3-1.

Table 2106.3-1
Moisture Content Requirements

For Compaction Requirements	Relative Moisture Content Requirements*
Minimum of 100 percent of Maximum Density	65 – 102 percent
Minimum of 95 percent of Maximum Density	65 – 115 percent
Quality compaction	65 – 102 percent
* As determined on Form G&B-105	

Correct moisture content in areas where moisture content test fails. Compaction tests taken in areas represented by failing moisture tests are not valid.

D Preparation of Embankment Foundation

When slopes are steeper than 1:4 (Vertical:Horizontal), construct steps before placing embankment Material. Construct the steps with a minimum width of 12 inches and a maximum height of 24 inches.

Compact the bottom of the excavation according to Table 2106.3-2.

Table 2106.3-2
Required Compaction for Bottom of Excavation

Excavation Depth Below Grading Grade *	Material Type	Required Compaction
< 30 inches	non-granular	100 percent of Maximum Density, LWD, and Quality Compaction
≥ 30 inches	non-granular	95 percent of Maximum Density or four passes of a roller ‖
Any depth	granular	100 percent of Maximum Density, LWD, penetration index, and Quality Compaction
For Structures any depth	non-granular	100 percent of Maximum Density, LWD, and Quality Compaction
For Structures any depth	granular	100 percent of Maximum Density, LWD, penetration index, and Quality Compaction
* Excavation below the planned Subgrade may be subject to 1402, "Contract Revisions" ‖ Use a pad foot roller weighing at least 25,000 pounds. The Engineer may waive the four pass requirement if the Subgrade will not support the roller or direct the Contractor to repair the Subgrade. Repairs are subject to 1402.5, "Extra Work."		

Remove surfacing and excavate an existing Road Core in accordance with the Contract. Then perform Subgrade preparation on the excavated portion and the new Road Core in accordance with 2112, "Subgrade Preparation," before placing new embankment Material.

E Excavating Operations

Obtain the Engineer's written approval before excavating beyond the limits and elevations established by the Contract.

Remove topsoil and stockpile separately.

Remove rock outcroppings from within the excavation limits as shown on the Plans.

Remove loosened rock from the backslopes.

Presplit rock back slopes steeper than 1:1 (Vertical:Horizontal). Control blasting operations to eliminate flying rock or debris.

Excavation below the planned Subgrade to correct unstable conditions may be subject to 1402, "Contract Revisions."

F Placing Embankment Materials

Remove snow, ice, and frozen soils from Road Core before placing embankment.

Install settlement plates, if required by the Contract. Do not disturb settlement plates.

Place embankments in uniform Lifts, parallel to the Plan Profile Grade, over the full width of the Roadway.

Construct each Lift of Material using uniform soil.

Protect Structures during placement of embankments.

Place granular Materials in the uppermost portion of the Subgrade.

Embankment Materials may not increase the moisture content of the underlying Material beyond the specified limit.

Maximum Lift thicknesses are controlled by the capability of the Equipment to uniformly compact the entire Lift in accordance with the following:

(1) For areas, except Structural backfill, the Engineer will restrict Lift thickness to no greater than 12 inches (loose thickness), when uniform results are not achieved.
(2) For Structural backfill, the maximum Lift thickness is 6 inches compacted (8 inches loose).
(3) The Engineer may allow thicker Lifts over saturated foundation soils. The top of the thicker Lift must be at least 4 feet below the Grading Grade.

Uniformly blend the entire thickness of each Lift before testing moisture content and compaction.

Disc soils with greater than 20 percent passing the No. 200 Sieve.

Stagger construction traffic uniformly over the full width of the Roadway embankment.

Use embankment Material with particle sizes no larger than specified in Table 2106.3-3:

Table 2106.3-3
Maximum Particle Size in Road Core

Location	Maximum Particle Size (Inches)
< 12 inches from Grading Grade	3
1 foot – 3 feet from Grading Grade	6
> 3 feet – 6 feet from Grading Grade	12
> 6 feet from Grading Grade	24
≤ 2 feet from a non-plastic Structure	3
≤ 2 feet from a plastic Structure	1
Areas where piling is to be placed	6

Remove surcharges as directed by the Contract.

Remove debris and stones exceeding 3 inches in its greatest dimension on the soil surface at the time of performing the final finishing and turf establishment operations. Dispose of debris and stones in accordance with 2104.3C, “Removal Operations.” Removal of pre-existing debris and stone encountered in the undisturbed topsoil on the Project will be paid for as Extra Work in accordance with 1402, “Contact Revisions,” as long as the Material was not contaminated or altered by the Contractor.

G Compacting Embankments and Backfills

Compaction tests taken in areas represented by failing moisture tests are not valid.

Uniformly compact each Lift according to Table 2106.3-4.

Table 2106.3-4
Required Compaction

Material Type	Location	Required Compaction *
Materials meeting the requirements of 3149.2B, "Granular and Select Granular Materials"	All depths and locations	100 percent specified density, Quality Compaction, penetration index, and LWD
Materials not meeting the requirements of 3149.2B, "Granular and Select Granular Materials"	> 3 feet below Grading Grade of Road Core, trails, or Sidewalks	95 percent specified density, and LWD when the Engineer performs a correlation test between 95 percent specified density, and an LWD.
Materials not meeting the requirements of 3149.2B, "Granular and Select Granular Materials"	≤ 3 feet below Grading Grade of Road Core, trails, or Sidewalks	100 percent specified density, Quality Compaction, and LWD
All Materials	All depths within an excavation trench and backfill of Structures, 2451, "Structure Excavations and Backfills"	100 percent specified density, Quality Compaction, and LWD
*See 2106.3G.1, "Specified Density," 2106.3G.2, "Quality Compaction," 2106.3G.3, "Penetration Index," and 2106.3G.4, Light Weight Deflectometer (LWD) Method" for compaction requirements.		

Compact Roadway embankment outside of the Road Core to the Quality Compaction requirements per 2106.3G.2, "Quality Compaction."

Compact the entire length and width of each Lift with a roller. Construction traffic does not replace the rolling requirement.

Compaction requirements on swamp backfills start when the Road Core embankment is 4 feet above the water elevation at the time of construction operations.

The Engineer may waive mechanical compaction requirements on embankment containing predominately rock.

Compact soils around Structures with appropriate Equipment or hand methods to prevent damage to adjacent Structures.

Correct or replace Materials in areas represented by a failing test.

Maintain the required compaction until the next Layer is placed.

G.1 Specified Density

Compact to meet the requirements of Table 2106.3-4.

G.2 Quality Compaction

Compact each Lift until there is no evidence of consolidation during compaction or under traffic, with no:

(1) Pumping – vertical displacement of the top surface of the compacted Layer, not directly under the vehicle tire
(2) Reaction – a movement back to a former or less advanced condition
(3) Yielding – giving under pressure (flexible)

(4) Cracking – cracking of Material on visible surface
(5) Lateral movement – sideways movement of the top surface

G.3 Penetration Index (PI)

Compact the entire Lift to achieve a dynamic cone penetration index (DPI) value per Table 2106.3-5.

Table 2106.3-5
Maximum Allowable Penetration for DCP

Grading Number *	Moisture Content ǁ	Maximum Allowable DPI, millimeter/blow
3.1 – 3.5	< 5.0	10
	5.0 – 8.0	12
	> 8.0	16
3.6 – 4.0	< 5.0	10
	5.0 – 8.0	15
	> 8.0	19
4.1 – 4.5	< 5.0	13
	5.0 – 8.0	17
	> 8.0	21
4.6 – 5.0	< 5.0	15
	5.0 – 8.0	19
	> 8.0	23
5.1 – 5.5	< 5.0	17
	5.0 – 8.0	21
	> 8.0	25
5.6 – 6.0	< 5.0	19
	5.0 – 8.0	24
	> 8.0	28

* As determined by Department Form G&B-203

ǁ Percent of dry weight
Note that a moisture test is not required if the Material meets the toughest requirements for the grading number.

G.4 Light Weight Deflectometer (LWD) Method

Compact the entire Lift to achieve an LWD target value as required per the LWD procedure in the *Grading and Base Manual*.

H Department Quality Assurance Testing (QA)

Test according to the *Schedule of Materials Control*.

H.1 Material Testing

Select Aggregate quality samples using the random sampling method in the *Grading and Base Manual*; additional samples and tests may be taken to delineate visually indicated Material failures. Select gradation samples from locations that are at risk of not meeting the Specification requirements.

H.2 Compaction Testing

Test for compaction using:

(1) Quality Compaction, and specified density or the LWD for Materials not meeting the requirements of Table 3149.2-1, Granular Material, or

(2) Quality Compaction, and specified density or penetration index or LWD for Materials meeting the requirements of Table 3149.2-1, Granular Material

Test for compaction in areas with the greatest rutting or deflection, near Structures, and in an area at least 1 foot from an unconfined edge.

After Contractor's correction of areas represented by failing tests, retest in areas with the greatest rutting or deflection.

For granular Materials with less than 6 percent passing the No. 200 Sieve, the Engineer may elect to only use the Quality Compaction method, 2106.3G.2, "Quality Compaction."

Use the specified density method for virgin Materials only.

The following method may be used in lieu of point testing (penetration index, specified density, or LWD) for Materials meeting Table 3149.2-1, Select Granular Material when the Material thickness is 18 inches or less and when not adjacent to Structures per 1103, "Definitions."

The Engineer may elect, with the concurrence of the Contractor, to have the Contractor test roll per 2111, "Test Rolling," Material meeting the requirements of Table 3149.2-1, Select Granular Material, in lieu of point compaction testing. If this method is adapted, the Contractor would be required to first place 3 inches of base on top of the Material meeting Table 3149.2-1, Select Granular Material before Test rolling. For areas failing Test rolling the Contractor is required to remove the base and recompact the Material meeting Table 3149.2-1, Select Granular Material, then place the base back, and retest roll. There is no additional compensation to the Contractor, if this method is adapted. Additionally, the Material meeting Table 3149.2-1, Select Granular Material, is not accepted, until acceptable Test rolling has occurred.

I Finishing Operations

Shape and maintain the Road Core to the required grade and cross-section and within the tolerance in accordance with 2112.3E, "Tolerances" until the next Layer is placed.

Perform earthwork finishing and topsoil placement operations concurrently to allow for timely placement of erosion control items. Shape and maintain disturbed areas outside the Road Core to final grade before placing erosion control items. Scarify the surface to a minimum depth of 3 inches before placing topsoil. Complete topsoil preparation, erosion control, and turf establishment, as required by 2574, "Soil Preparation" and 2575, "Establishing Vegetation and Controlling Erosion."

J Disposition of Excavated Material

Excavation and embankment Material not utilized on the Project becomes the property of the Contractor, except obtain written authorization from the Engineer before removing topsoil or granular Material from the Project.

Dispose of these Materials in accordance with a disposal Plan approved by the Engineer. The disposal Plan must comply with applicable environmental regulations, permit requirements, and 2104, "Removing Pavement and Miscellaneous Structures." Disposal of Materials before acceptance of the disposal Plan is unauthorized Work in accordance with 1512, "Unacceptable and Unauthorized Work."

2106.4 METHOD OF MEASUREMENT

A Excavation Material

The Engineer will measure and calculate excavated Material quantities according to 1901.5A "Excavated Volume (EV) – Cubic Yard."

Quantities are limited to measurements within specified construction limits and variances authorized by the Engineer.

The Engineer will take measurements to determine the limits of excavation Material.

A.1 Rock Excavation

The Engineer will include the following in the measurement for rock excavation:

(1) Overbreakage if the plane of the bottom of the excavation falls within a Layer or stratum of rock
(2) 6 inches overbreak allowance outside the grading section or as indicated in the Plans
(3) 24 inches measured horizontally, overbreak allowance outside the backslopes for hard rock types

The Engineer will not provide an allowance for overbreak of pre-split backslopes.

B Embankment Material

The Engineer will measure embankment Material quantities by volume in accordance with 1901.5B, “Compacted Volume (CV) – Cubic Yard.”

C Stabilizing Aggregate

The Engineer will measure Stabilizing Aggregate quantities by volume in accordance with 1901.5B, “Compacted Volume (CV) – Cubic Yard” or by the ton, in accordance with 1901.8, “Mass.”

2106.5 BASIS OF PAYMENT

The Contract Unit Price for accepted quantities of Excavation and Embankment – compacted volume method items includes: the costs of production, testing, disposal, delivery, placement, drying, water and watering, compaction, and finishing.

The Department will pay for stripping and stockpiling topsoil as excavation – common.

The Department will pay for placing topsoil as common embankment.

The cost for Subgrade preparation under 2106.3D, “Preparation of Embankment Foundation,” is included in the excavation 2106, “Excavation and Embankment – Compacted Volume Method,” bid items.

A Monetary Adjustments

The Department must apply Incentives and Disincentives and may apply monetary deductions for Excavation and Embankment – Compacted Volume Method. The amounts of these adjustments are deemed reasonable.

The Department will pay an additional $2.00 per cubic yard when the Engineer reclassifies Excavation - common to Excavation - channel and pond.

The Department will pay an additional $200.00 per cubic yard when the Engineer reclassifies Excavation - common, Excavation - Subgrade, or Excavation - channel and pond to Excavation - rock. The Department can only apply this price adjustment if the Contract does not contain Rock excavation and cannot exceed 250 cubic yard.

The Department will pay an additional $200.00 per cubic yard when the Engineer reclassifies Excavation - channel and pond to Excavation - rock channel. The Department can only apply this price adjustment, if the Contract does not contain Rock channel excavation and cannot exceed 25 cubic yard.

The Department will pay for Excavation - muck deeper than the depth shown on the Plans, in accordance with Table 2106.5-1.

Table 2106.5-1
Monetary Deductions for Excavation - Muck

Depth Below Natural Surface	Compensation
0 feet – 15 feet	muck excavation Unit Price
> 15 feet – 20 feet	muck excavation Unit Price plus $0.60 per cubic yard
> 20 feet – 25 feet	muck excavation Unit Price plus $1.00 per cubic yard
> 25 feet	negotiated price
Note: These price adjustments are payment in full for all additional costs incurred. Exception: Compensation for additional muck excavation may be subject to the provisions of 1402, "Contract Revisions."	

B Schedule

The Department will pay for Excavation and Embankment – compacted volume method on the basis of the following schedule:

Item No.	Item	Unit
2106.507	Excavation – Common	cubic yard
2106.507	Excavation – Rock	cubic yard
2106.507	Excavation – Muck	cubic yard
2106.507	Excavation – Subgrade	cubic yard
2106.507	Excavation – Channel and Pond	cubic yard
2106.507	Excavation – Rock Channel	cubic yard
2106.507	Granular Embankment (CV)	cubic yard
2106.507	Select Granular Embankment * (CV)	cubic yard
2106.507	Select Granular Embankment Super Sand (CV)	cubic yard
2106.507	Common Embankment (CV)	cubic yard
2106.507	Stabilizing Aggregate (CV)	cubic yard
2106.509	Stabilizing Aggregate	Ton

Notes:
* Specify basis of percent modification (e.g. 5 percent, 7 percent, 10 percent, etc.)

2108 GEOSYNTHETIC CONSTRUCTION MATERIALS

2108.1 DESCRIPTION

This Work consists of providing and placing geosynthetics used for one or more of the following:

(1) Separation of dissimilar or softer soils to prevent mixing, pumping, and contamination.
(2) Provide stability during compaction.
(3) Provide reinforcement and minimize differential movement.
(4) Promote and enhance filtration and drainage in embankment.
(5) Provide confinement of granular or topsoil to construct walls, slopes, stabilize Aggregate base course, or promote turf establishment.

2108.2 MATERIALS

Provide the type(s) of geosynthetics as shown or allowed in the Plans.

A Geotextiles **3733**

B Geogrids **3733**

Indiana DOT Test Method 508 Field Determination of Deflection Using Lightweight Deflectometer

INDIANA DEPARTMENT OF TRANSPORTATION
DIVISION OF MATERIALS AND TESTS

FIELD DETERMINATION OF DEFLECTION USING LIGHT WEIGHT DEFLECTOMETER
ITM No. 508-19

1.0 SCOPE

1.1 This test method covers the determination of deflections with a Light Weight Deflectometer (LWD), also known as Portable Impulse Plate Load Test Device.

1.2 The LWD may be used for structure backfill, coarse aggregates, chemically modified soils, or as directed by the Department. Only structure backfill size 1 1/2 in. and coarse aggregate sizes No. 43, 53, and 73 shall be tested with the LWD.

1.3 The LWD test relates deflection with the Dynamic Elastic Modulus and is defined as the maximum axial stress of a material in sinusoidal loading divided by the maximum axial strain during that loading.

1.4 The values stated in SI metric units are to be regarded as standard, as appropriate for a specification with which this ITM is used.

1.5 This ITM may involve hazardous materials, operations, and equipment and may not address all of the safety problems associated with the use of the test method. The user of the ITM is responsible for establishing appropriate safety and health practices and determining the applicability of regulatory limitations prior to use.

2.0 REFERENCES.

2.1 ASTM Standards.

E2835 Measuring Deflections using a Portable Impulse Plate Load Test Device

3.0 TERMINOLOGY. Definitions for terms and abbreviations shall be in accordance with the Department's Standard Specifications, Section 101 and the following:

3.1 Structure backfill. In accordance with 904.

3.2 Chemically Modified Soil. Soil that has been modified with portland cement, fly ash, lime, cement by-product, or a combination of these materials

4.0 SIGNIFICANCE AND USE. This ITM shall be used to determine the surface deflection resulting from an application of an impulse load using the LWD. The resulting deflections are used to determine the stiffness of structure backfill, coarse aggregates, and chemically modified soil in embankments and other applications.

5.0 APPARATUS.

5.1 Force-Generating Device (Appendix A), 10 kg ± 0.1kg falling weight with a guide system, lock pin and spring assembly. The mass of the guide rod is 5 kg ± 0.25 kg and the maximum impact force is 7.07 kN. The fixed drop height shall be in accordance with the manufacturer recommendation.

5.2 Loading Plate, made of steel, having dimensions of 300 mm in diameter and 20 mm in thickness. The plate shall have two handles and weigh 15 kg ± 0.25 kg.

5.3 Deflection Sensor, capable of measuring the maximum vertical movement with an accelerometer. The accelerometer is required to be attached to the center of the plate.

5.4 Data Processing and Storage System, capable of displaying and recording the loading data, deflection data, and the test location for each test

5.5 Miscellaneous equipment such as a spade, broom, trowel, and cotton gloves

6.0 TEST AREA PREPARATION. The test area shall be leveled so that the entire undersurface of the load plate is in contact with the material being tested. Loose and protruding material shall be removed. If required, any unevenness shall be filled with fine sand. The test shall not be conducted if the temperature is below freezing. The test area shall be at least 1.5 timeslarger than the loading plate.

7.0 PROCEDURE.

7.1 Rotate the loading plate approximately 45° back and forth to seat the plate. The plate should not move laterally with successive drops of the falling weight.

7.2 Place the force generating device onto the loading plate. Hold the guide rod perpendicular to the loading plate.

7.3 Conduct three seating drops by raising the falling weight to the release mechanism, allowing the hammer to fall freely, and catching the falling weight after the weight rebounds from striking the plate.

7.4 Following the three seating drops, conduct three drops of the falling weight and record the average of the last three drops shown on the LWD display. A test is considered invalid if the operator does not catch the falling weight after the weight rebounds from the load plate or the load plate moves laterally. A new test location is required at least 2 ft away from the original location of testing when the test is invalid. If the change in deflection is 10 % or greater for any two consecutive drops, the material shall require additional compaction or aeration and steps 7.1, 7.2, 7.3, and 7.4 shall be repeated.

7.5 Record the smartcard number and the test drop deflection measurements on the data collection form TD-409 LWD.

8.0 VERIFICATION TESTING. Perform LWD Verification Testing annually in accordance with ASTM E2835 with complete equipment identification. This verification shall be provided to the Engineer when requested.

9.0 REPORT. Report the average deflection (which is the average of the last three drops shown on the LWD display) in mm. This value is one of the three tests required at a random station in accordance with 203.24.

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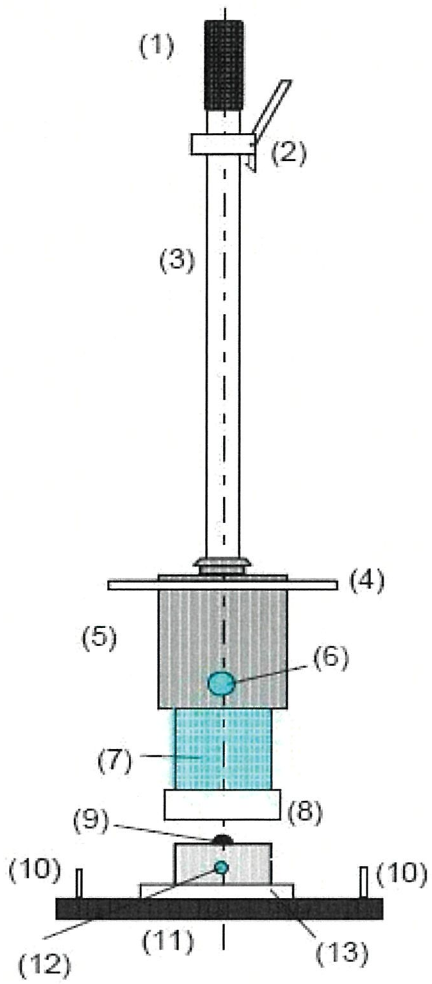

(1) grip
(2) top fix and release mechanism
(3) guide rod
(4) round grip
(5) 10 kg - falling weight
(6) lock pin
(7) set of steel springs
(8) anti tipping fixture
(9) load centre ball
(10) carry grip
(11) loading plate diameter (300 mm)
(12) socket for the connection to the electronic device
(13) adapter plate

Indiana DOT Standard Specifications 2022, Section 203.24 Method of Making Strength, Stiffness and Density Tests pipe in accordance with 715.02(d) and shall be enclosed in geotextile for underdrains in accordance with 918.02. Lateral underdrains shall be spaced a maximum of 100 ft longitudinally along the centerline of the embankment, shall outlet into the roadside ditch on each side of the embankment, shall extend a minimum of 8 ft horizontally into the embankment, and shall be sloped at a minimum of 0.2%.

Underdrain outlet protectors in accordance with 718.06 shall be installed at the outlet end of each lateral underdrain.

Coal ash shall be encased on all sides with cohesive soil. The cohesive soil shall be a silty loam, sandy clay, silty clay, sandy clay loam, clay, or a silty clay loam in accordance with 903.02. All cohesive soils shall have a minimum clay content of 10%.

Encasement shall be as follows:

Total Finished Embankment Height	Encasement (measured horizontally)
Less than 10 ft	2 ft
10 ft to 20 ft	3 ft
Greater than 20 ft	4 ft

Encasement material shall be placed and compacted concurrently with the coal ash lifts.

The top of the coal ash embankment shall be encased with a minimum of 1 ft of cohesive soil beneath the bottom of subgrade.

203.24 Method of Making Strength, Stiffness and Density Tests

The strength of chemically modified or compacted soils will be determined by DCP in accordance with ITM 509.

The stiffness of chemically modified soils or aggregates will be determined by the LWD in accordance with ITM 508.

The density of soils and aggregates, as a percent of compaction, will be based on the maximum dry densities unless otherwise specified or directed.

DCP field compaction tests will be performed in accordance with 203.23. LWD and density field compaction tests will be performed in accordance with this section. The required compaction shall be obtained before additional material is placed.

(a) Laboratory

The DCP criteria will be established on representative soils by performing ASTM D1140, AASHTO T 88, AASHTO T 89, AASHTO T 90, and AASHTO T 99 using Method A for soils and Method C for granular materials.

The optimum moisture content, maximum dry density, and gradation of aggregates will be determined by performing AASHTO T 99 Method C, AASHTO T 11, and AASHTO T 27 on representative samples of the aggregates.

(b) Field

The soil strength of compacted soils or compacted chemically modified soils will be determined by DCP in accordance with ITM 509 and the stiffness of chemically modified soils or aggregates will be determined by LWD in accordance with ITM 508. The moisture content will be determined in accordance with ITM 506 or AASHTO T 255.

As an alternative, in situ field density may be determined in accordance with AASHTO T 191, except as listed below. The maximum dry density of the soil will be determined by ITM 512

1. If AASHTO T 191 is used, the sand used for the test shall be silica sand in accordance with the gradation as follows:

   Passing the No. 20 (850 µm) sieve - 98 to 100%
   Passing the No. 40 (425 µm) sieve - 0 to 35%
   Passing the No. 70 (212 µm) sieve - 0 to 2%

   Sand such as Wedron Silica Sand No. 4075 or Ottawa 2.8 Blasting Sand has been found to be acceptable.

2. If particles larger than those that can pass through a No. 4 (4.75 mm) sieve for soil and a 3/4 in. (19 mm) sieve for granular material are encountered, corrections shall be made so that the density obtained is for the minus No. 4 (4.75 mm) or 3/4 in. (19 mm) only. After the densities are determined, the percent compaction will be computed by the following formula:

$$\text{Percent Compaction} = \frac{\text{In Place Density, pcf}}{\text{Maximum Density, pcf}} \times 100$$

3. Other approved types of field density tests may be used for control purposes after density values corresponding to those obtained by either of the methods set out above have been established.

4. All references to soils in these methods of tests shall be interpreted to mean either or both soil and granular materials.

Acceptance testing of chemically modified soils and coarse aggregates will be determined by LWD testing in accordance with ITM 508. The allowable deflection will be determined from a test section or will be specified. Test sections shall be constructed in accordance with ITM 514 in the presence of a representative of the Geotechnical Engineering Division for other materials not included in the Tables to determine the maximum allowable deflection. The compaction procedures shall be in accordance with 203.23, 215, 301, 302, and 303. Proofrolling of compacted aggregate shall be performed in accordance with 203.26.

The allowable average deflection and maximum deflection for chemically modified soils and aggregate over chemically modified and untreated soils shall be in accordance with the following:

Table 1. Allowable Average Deflection and Maximum Deflection for Chemically Modified Soils and Aggregate over Chemically Modified Soils.

Material Type	Allowable Average Deflection (mm)	Maximum Deflection at a Single Test Location (mm)
Lime Modified Soil	≤ 0.30	0.35
Cement Modified Soil	≤ 0.27	0.31
Aggregate over Lime Modified Soil	≤ 0.30	0.35
Aggregate over Cement Modified Soil	≤ 0.27	0.31

Table 2. Aggregate over Untreated Soils: Where Proofrolling Can Be Performed

Material Thickness	Allowable Average Deflection (mm)	Maximum Deflection at a Single Test Location (mm)
6 in. Thick Coarse Aggregate No. 53	≤ 0.51	0.57*
12 in. Thick Coarse Aggregate No. 53	≤ 0.34	0.40**
18 in. Thick Coarse Aggregate No. 53	≤ 0.31	0.35**

* When deflection exceeds this value, the area shall be recompacted or undercut as directed. The failed area will be delineated prior to excavation. Deflection will be measured based on the top 6 in. thick coarse aggregate No. 53 material placed for undercut.

** The Contractor shall recompact the coarse aggregate No. 53 in accordance with 301.06.

Table 3. Aggregate over Untreated Soils:
Where Proofrolling Cannot be Performed

Material Thickness	Allowable Average Deflection (mm)	Maximum Deflection at a Single Test Location (mm)
6 in. Thick Coarse Aggregate No. 53	≤ 0.60	0.65*
12 in. Thick Coarse Aggregate No. 53	≤ 0.47	0.52**
18 in. Thick Coarse Aggregate No. 53	≤ 0.44	0.49**

* When deflection exceeds this value, the area shall be recompacted or undercut as directed. The failed area will be delineated prior to excavation. Deflection will be measured based on the top 6 in. thick coarse aggregate No. 53 material placed for undercut.

** The Contractor shall recompact the coarse aggregate No. 53 in accordance with 301.06.

Note:

The Engineer will perform the moisture test on in-situ soils prior to placement of coarse aggregate. If the result of the moisture test is > 13%, the Engineer will contact the Department's Geotechnical Engineering Division.

Acceptance of the compaction of chemically modified soils or aggregate will be determined by averaging three LWD tests obtained at a random station determined in accordance with ITM 802, for each 1,400 cu yds of chemically modified soil or for each 800 t of compacted aggregate. Where the construction area is 8 ft wide or more, the location of the three tests will be at 2 ft from each edge of the construction area and at 1/2 of the width of the construction area. Where the construction area is less than 8 ft wide, the location of the three LWD tests will be spaced at 1/2 of the width of the construction area and spaced 5 ft apart in the longitudinal direction. The average deflection shall be equal to or less than the maximum deflection allowed in the tables above or determined by the test section.

203.25 Embankment Without Stiffness Control

When aggregate is used for embankment construction and it is not possible to perform stiffness testing in accordance with ITM 508 or strength testing in accordance with ITM 509, such material shall be compacted with several passes of crawler-tread equipment or with approved vibratory equipment, or both. The equipment weight shall be at least 10 t. The materials shall be placed in lifts not to exceed 9 in. loose measurements, or as directed by the Engineer. Each lift shall be compacted with a minimum of five passes. The tread areas shall overlap enough on each trip so that the entire embankment is compacted uniformly. When the embankment reaches 24 in. below the proposed subgrade elevation, proofrolling shall be performed in accordance with 203.26. Proofrolling shall also be performed at every 5 ft of fill placed. Any defect shall be corrected as directed. Upon acceptance, a layer of geotextile in accordance with 918.02(a) Type 2B, shall be placed and the remaining embankment shall be constructed with No. 53 aggregate in accordance with 301.

At locations inaccessible to the above compacting equipment, the required compaction shall be obtained with approved mechanical tamps or vibrators, in which

Indiana DOT Standard Specifications 2022 Special Provisions, Section 218-R-576 QC/QA For Soil Fill Sections and QC/QA For Subgrade

218-R-576 QC/QA FOR SOIL FILL SECTIONS AND QC/QA FOR SUBGRADE

(Adopted 02-18-21)

The Standard Specifications are revised as follows:

SECTION 218, BEGIN LINE 1, DELETE AND INSERT AS FOLLOWS:

SECTION 218 – ~~BLANK~~*QC/QA FOR SOIL FILL SECTIONS AND QC/QA FOR SUBGRADE*

218.01 Description

This work shall consist of incorporating QC/QA processes in the construction of soil fill sections using a combination of borrow, embankment, and excavation, or in the construction of subgrades, all in accordance with 105.03, 203, and 207.

218.02 Quality Control

QC testing shall include DCP in accordance with ITM 509, LWD in accordance with ITM 508, moisture in accordance ITM 506 or AASHTO T 255, and one-point proctor in accordance with ITM 512.

(a) Quality Control Plan

The Contractor shall prepare and submit a QCP in accordance with ITM 803. The QCP shall be submitted to the Engineer at least 15 days prior to the Contractor's planned start date for soil or subgrade work. The QCP will be returned either as accepted or showing changes or corrections required within 15 days of receipt. If required to be changed or corrected, the QCP shall be resubmitted until it is accepted. Soil and subgrade operations shall not begin until the Contractor receives written notice from the Engineer that the QCP has been accepted.

(b) Quality Control Manager and Technician

The Contractor shall provide a QC Manager and QC Technician in accordance with ITM 803, section 4.5. The QC Technician shall be qualified in accordance with the Department's Division of Materials and Tests Directive 107 for ITM 506, ITM 508, ITM 509, and ITM 512, and AASHTO T 255.

CONSTRUCTION REQUIREMENTS

218.03 General Requirements

QC testing shall be performed in accordance with the QCP and ITM 803 section 14.6 or section 14.7.

Soil Management shall be in accordance with the QCP and ITM 803. Adjustments shall be made to compaction procedures when the soil type changes.

The Contractor shall provide documentation in accordance with the QCP and ITM 803 by the end of the following business day or before the next QA test, whichever comes first.

218.04 Test Sections

Test sections shall be constructed in accordance with the QCP.

Test sections shall be constructed for non-chemically modified soils in accordance with 203, ITM 513, and ITM 803 to determine compaction pattern and rolling passes necessary to meet the DCP requirements. The roller equipment selected for use and rolling pattern shall be based on best compaction practice for the soil types encountered on the contract. Intelligent compaction methods described in ITM 513 may be used but will not be required. The soil in the test section shall meet the requirements of 203.

218.05 Acceptance of Soil Compaction

Acceptance of the compaction of the soils and subgrade will be based on the results of measurements and tests performed by the Engineer.

The moisture content and compaction acceptance of the soil fill sections will be determined in accordance with 203.23 and 203.24. The moisture content and compaction acceptance of chemically modified soils will be determined in accordance with 215 or 207.

The Contractor shall notify the Engineer when a lift area is ready for acceptance testing. Testing will be performed at random locations in accordance with ITM 802 at the frequency described below.

<table>
<tr><th colspan="3">FREQUENCY OF QA TESTING</th></tr>
<tr><th>Test</th><th>Soils</th><th>Subgrade</th></tr>
<tr><td>Moisture Content</td><td>1 per day</td><td>1 per every 4 h</td></tr>
<tr><td rowspan="2">Strength or Stiffness</td><td rowspan="2">3 per 2,000 cu yd.</td><td>3 per 2,000 cu yds</td></tr>
<tr><td>3 per 1,400 cu yds for chemically modified soil</td></tr>
<tr><td>Gradation</td><td>---</td><td>1 per every 2,500 cu yds of chemically modified soil</td></tr>
<tr><td>Maximum Dry Density</td><td>1 at start of work and 1 for every change in soil type</td><td>---</td></tr>
<tr><td>One Point Proctor</td><td>1 per every 3 days and 1 for every change in soil type</td><td>---</td></tr>
<tr><td>Spreading</td><td>---</td><td rowspan="2">ITM 516</td></tr>
<tr><td>Adjustment of Chemical</td><td>---</td></tr>
</table>

218.06 Deficiencies

Individual soil fill sections or subgrade locations that do not meet the requirements of 203.23 and 203.24, will be considered deficient. All locations exhibiting deflections or rutting in excess of the values shown in 203.26, as determined by the Department, will also be considered deficient.

When a deficiency is identified at the random location or by additional selective testing, the Contractor shall investigate and correct the deficiency by reworking the location in accordance with the QCP. The Engineer will subsequently randomly select at least two additional locations within the remaining lift area and perform acceptance testing. If either of the two additional locations fails to meet the acceptance criteria, then the entire lift area shall be evaluated by the Contractor in accordance with the QCP and *reworked as necessary. All reworked areas shall be proofrolled in accordance with 203.26 before acceptance testing is resumed in that lift area.*

Locations where rework is not required may still be reworked at the Contractor's option in accordance with the QCP. Reworked areas are subject to further review for deflections or rutting at the discretion of the Department.

218.07 Method of Measurement

Performing the QC services portion of the work, including but not limited to, equipment required for the QC/QA soil process, all quality control procedures including the QCP, on-site training, testing facility, construction of test sections, QC testing, inspection, and other professional services necessary will not be measured for payment.

218.08 Basis of Payment

Where a QC/QA soil fill section or subgrade has not been constructed and conditions exist below the specified subgrade compaction depth that prevent achieving the specified compaction, payment for correcting such conditions will be made based on the directed method of treatment.

All costs for performing the QC services portion of the work, including but not limited to, equipment required for the QC/QA soil process, all quality control procedures including the QCP, on-site training, testing facility, construction of test sections, QC testing, inspection, and other professional services necessary shall be included in the lump sum items below.

Payment will be made under:

Pay Item	***Pay Unit Symbol***
QC/QA Services for Soil Fill Sections	*LS*
QC/QA Services for Subgrade	*LS*

Nebraska Department of Roads Standard Test Method T2835 Deflection Measurement of Soils Using a Lightweight Deflectometer (LWD)

NEBRASKA DEPARTMENT OF ROADS
NDR STANDARD TEST METHOD T 2835

DEFLECTION MEASUREMENT OF SOILS USING A LIGHTWEIGHT DEFLECTOMETER (LWD) *Modified*

ASTM Designation: E 2835

A.1 SCOPE

1. This method covers the measurement of soil deflection by use of a type of plate-bearing test. A force is generated by a falling weight dropped onto a plate which is resting on the material to be tested.

2. The falling weight is raised to a preset height of 720 mm (28 in.). When dropped, the weight will apply the required force pulse. The weight is dropped and the resultant surface deflection is measured using the LWD's instrumentation.

3. The deflection values resulting from the applied force at each test location is recorded in millimeters, or as appropriate.

4. The drop height of the falling weight is fixed and shall not be changed by the user.

A.2 EQUIPMENT

The LWD consists of the following components (See Figure 1).

1. Handle Grip – Used to hold the LWD guide rod vertical and to limit upward movement of the falling weight. Note, there is a bubble level at the top to help hold the guide rod plumb.

2. Release Mechanism – Holds the falling weight at a constant height and when the release mechanism is pressed, allows the falling weight to drop freely.

3. Guide Rod – Allows the falling weight to drop freely the required distance of 720 mm (28 in.).

4. Falling Weight Grip – Provides a grip for the operator to catch the falling weight after it impacts the plate and to raise the falling weight to the top release mechanism.

5. 10-kg Falling Weight – Is manually raised to the bottom of the grip and held in place with the release mechanism.

6. Lock Pin – When pushed in the pin keeps the weight from moving up the guide rod during storage and transport. When pin is pulled the weight is free to move up and down the guide rod.

7. Steel Spring – Provides a buffer system that transmits the load to plate resting on the material being tested. The steel spring is protected by a sealed rubber boot.

8. Anti-Tipping Fixture – Prevents the guide rod and falling weight from tipping when standing freely on the load center ball.

9. Load Center Ball – Serves as a connector between the anti-tipping fixture and the loading plate.

10. Carry Grip – Provides handles for easier carrying of the loading plate by the operator.

11. Loading Plate – Provides an approximate uniform distribution of the load applied from the falling weight to the surface being tested. Loading plate has a diameter of 300 mm (11.8 in.).

12. Cable – Used to connect the loading plate sensor to the recording and storage instrument.

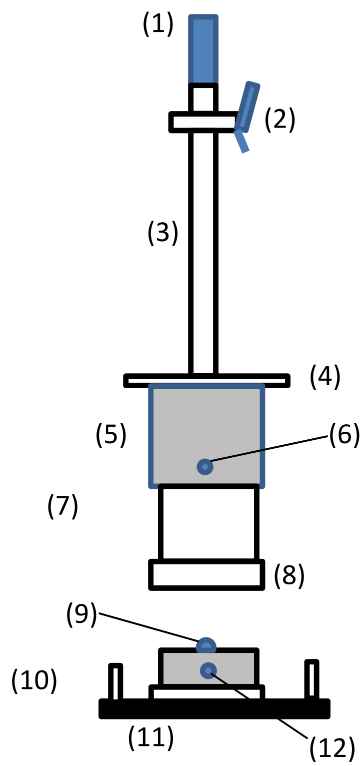

Figure 1. LWD individual components.

13. Measuring Instrument – Data processing device that records, displays, and stores deflection data (See Figure 2).

Figure 2. Hand-Held Measuring Instrument

B.1 STANDARDIZATION

1. Repeatability testing shall be performed:

   a. Upon receipt of a newly purchased device.
   b. Prior to recommissioning a device after calibration.
   c. When measurements are questionable or are no longer repeatable.
   d. Annualy or after 10,000 test measurements.

B.2 REQUIREMENTS

1. Designate a test pad location at the office or location in which the device is being stored that is bare, sound concrete with a minimum thickness of 6 inches.

2. Using the load plate as a template mark the the circular location of the test pad area for future reference of the test pad location.

3. Position the loading plate on the prepared test surface.

4. Place the upper portion of the LWD (falling weight and guide rod) on top of the loading plate, using the load center ball as a guide.

5. Plug in chord from the hand-held measuring instrument into load plate and turn on measuring instrument.

6. Press "OK" to start measurements. Turn off Pre-Load Settings[1].

7. Perform 9 falling weight drops using the following following procedure for each drop:

   a. Raise the falling weight to the preset drop height and snap falling weight into the release mechanism.
   b. Adjust guide rod to plumb, using the bubble level as a guide.
   c. Release the falling weight, allowing it to free-fall.
   d. Catch the falling weight after it rebounds off the load plate.
   e. Snap weight into release mechanism.[2]

   [1]Note: Refer to LWD Repeatability Form.
   [2]Note: Record deflection measurements after drops 1 through 9.

8. Use the following calculations to determine the repeatability of deflection measurements:

   a. $S_{max} - S_{min} \leq 0.04$ mm

      i. S_{max}= max of $(S_1,S_2,S_3,S_4,S_5,S_6,S_7,S_8,S_9)$
      ii. S_{min}= min of $(S_1,S_2,S_3,S_4,S_5,S_6,S_7,S_8,S_9)$
      iii. Definitions:
         a. S_{max} = maximum deflection measurement, mm.
         b. S_{min} = minimum deflection measurement, mm.

b. $|S_{mean} - S_i| \le 0.02$ mm

i. S_{mean} = average deflection for tests (S_1,S_2,S_3,S_4,S_5,S_6,S_7,S_8,S_9)
ii. S_i = deflection measurements for drop *i* (where *i* = 1 to 9)

9. Repeat testing on test pad when the calculations in step 8 are not met. This step is taken to remove operator errors or extraneous factors, if any, that may have caused non-repeatable results.

10. Submit device for calibration when the calculations in step 8 are still not met after repeat testing.

C.1 TESTING CONSTRAINTS

1. Perform tests immediately after compaction.

2. Perform testing in an air temperature range of 32 to 120 degrees Fahrenheit.

3. Ensure soil is not frozen.

C.2 SITE TESTING LOCATION AND PREPARATION

1. Create a smooth and level spot that allows the LWD guide rod to remain vertical and prevents the loading plate from sliding during testing.

2. Prepare a test area that is 1.5 times larger than the diameter of the loading plate (1.5-ft square).

3. Remove any disturbed material and any additional material as necessary to expose the top of the material to be tested.

4. Position the loading plate on the prepared test surface. Using the loading plate handles, turn the loading plate left and right to help seat the plate.

5. Place the upper portion of the LWD (falling weight and guide rod) on top of the loading plate, using the load center ball as a guide.

6. Plug in chord from the hand-held measuring instrument into load plate and turn on measuring instrument.

7. Press “OK” to start measurements.

8. Perform six falling weight drops using the following procedure for each drop:

f. Raise the falling weight to the preset drop height and snap falling weight into the release mechanism.
g. Adjust guide rod to plumb, using the bubble level as a guide.
h. Release the falling weight, allowing it to free-fall.
i. Catch the falling weight after it rebounds off the load plate.
j. Snap weight into release mechanism.[1,2]

[1]Note: Record deflection measurements after the 4^{th}, 5^{th}, and 6^{th} drops and the average deflection after the sixth drops. The device automatically saves the data to the memory card.
[2]Note: Press “OK” after test is complete to view the average test result.

9. Write down LWD test number from measurement device (result #) and record all pertinent information onto LWD field Test Form.

10. Repeat deflection measurements at another location (move approximately 1.5-ft longitudinally) when the following conditions occur during the test[3]:

    a. The falling weight is not caught after rebound.
    b. The load plate slides.
    c. The falling weight is not dropped from the calibrated height.

    [3]Note: A faulty test cannot be repeated at the same location.

11. Obtain the moisture content sample from approximately 3 to 9 inches below the surface of the LWD test location. Perform moisture content test using either the burner/stove, hot-plate, speedy, microwave, or oven-dry method. Record the moisture content on the LWD Field Test Form.

D.1 SAFETY

1. Keep back straight and lift with legs to help prevent injury when elevating and dropping the falling weight.

2. Keep hands and extremeties from beneath the falling weight or load plate to avoid injury.

3. Secure falling weight into lower position with lock pin prior to transport to prevent injury from movement of the falling weight.

E.1 MAINTENANCE AND HANDLING

1. Inspect equipment for necessary repairs. Ensure rubber boot around steel spring provides a tight seal.

2. Store LWD in dry place when not in use.

3. Make sure guide rod is not directly resting on soils.

4. Clean the LWD by removing any dirt with a dry cloth or with compressed air. Do not use grease or oil on the guide rod.

5. Check the drop height to ensure that slippage of the release mechanism has not occurred. If slippage has occurred, correct the drop height and tighten set-screws on release mechanism.

6. Recharge battery after 3 to 12 hours of use or at 3-month intervals when not in use.

7. Charge or replace the battery when charging level is less than 50 percent.

F.1 CALIBRATION

1. Calibrate the force generation device and deflection sensor as recommended by the Manufacturer, when deflection measurements are no longer repeatable, or after 10,000 measurements, whichever comes first.

ASTM E2583-07 (2020) Standard Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)

Designation: E2583 – 07 (Reapproved 2020)

Standard Test Method for Measuring Defections with a Light Weight Defectometer (LWD)[1]

This standard is issued under the fixed designation E2583; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of deflections of paved and unpaved surfaces with a Light Weight Deflectometer (LWD). This device is also referred to as a Portable Falling-Weight Deflectometer (PFWD). The LWD is lightweight, portable, and generally used for testing unbound pavement layers. The deflections measured using an LWD can be used to determine the stiffness of bound and unbound pavement surfaces using appropriate back or forward calculation analysis techniques.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D4695 Guide for General Pavement Deflection Measurements

2.2 *Other Standards:*[3]

FHWA-HRT-06-132 Version 4.1 Long-Term Pavement Performance Program Manual for Falling Weight Deflectometer Measurements

3. Summary of Test Method

3.1 This test method is a type of plate-bearing test. The load is a force pulse generated by a falling weight (mass) dropped on a buffer system that transmits the load pulse through a plate resting on the material to be tested. The test apparatus may be hand held or moved around with a dolly-type device.

3.2 The weight is raised to the height that, when dropped, will impart the desired force pulse. The weight is dropped and the resulting vertical movement or deflection of the surface is measured using suitable instrumentation. Multiple tests at the same drop height (different heights are optional) may be performed at the same location.

3.3 The peak deflection resulting from the force pulse at each location is recorded in micrometres, millimetres, mils, or inches, as appropriate.

3.4 The peak force imparted by the falling weight is recorded as the force in kN or lbf, or as the mean stress (the force divided by the load plate area) in kN/m^2 (kPa) or psi, as appropriate.

4. Signifcance and Use

4.1 This test method covers the determination of surface deflections as a result of the application of an impulse load. The resulting deflections are measured at the center of the applied load and may also be measured at various distances away from the load. Deflections may be either correlated directly to pavement performance or used to determine *in-situ* material characteristics of the pavement layers. Some uses of data include quality control and quality assurance of compacted layers, structural evaluation of load-carrying capacity, and determination of thickness requirements for highway and airfield pavements (see Guide D4695).

NOTE 1—Since pavement and subgrade materials may be stress

[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.41 on Pavement Testing and Evaluation.

Current edition approved Nov. 1, 2020. Published November 2020. Originally approved in 2007. Last previous edition approved in 2015 as E2583 – 07 (2015). DOI: 10.1520/E2583-07R20.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from the Federal Highway Administration (FHWA), 1200 New Jersey Ave., SE Washington, DC 20590.

dependent, care must be taken when analyzing LWD test data on unbound materials so that the applied stress will closely match the stress value applied by the design wheel load at the pavement surface.

NOTE 2—The volume of the pavement and subgrade materials affected by the load is a function of the magnitude of the load. Therefore, care must be taken when analyzing the results, since the data obtained by the LWD may be obtained from a smaller volume of the unbound materials than under the influence of a heavy moving wheel load at the pavement surface.

5. Apparatus

5.1 *Instrument System,* conforming to the following general requirements:

5.2 *Instruments Exposed to the Elements,* shall be operable in the temperature range of –10 to 50 °C (10 to 120 °F) and shall tolerate relatively high humidity, rain or spray, and all other adverse conditions such as dust, shock, or vibrations that may normally be encountered.

5.3 *Force-Generating Device,* (a falling weight) with a guide system. The force-generating device shall be capable of being raised to a predetermined height and dropped. The resulting force pulse transmitted to the pavement shall be capable of providing a half-sine or haversine shaped load pulse, with a time of loading of between 20 and 40 msecs, and shall be reproducible within the requirements of 7.1.

5.4 *Falling Weight,* designed to operate with negligible friction or resistance.

5.5 *Load Plate,* capable of an approximately uniform distribution of the impulse load on the surface. The instrument shall be suitably constructed to allow pavement deflection measurements at the center of the point of impact, through a hole in the center of the load plate.

5.6 *Deflection Sensor(s),* capable of measuring the maximum vertical movement and mounted in such a manner as to minimize angular rotation with respect to its measuring plane at the maximum expected movement. The number and spacing of the sensors is optional and will depend upon the purpose of the test and the pavement layer characteristics. Sensors may be of several types such as displacement transducers, velocity transducers, or accelerometers.

5.7 *Data Processing and Storage System*—Load and deflection data shall be displayed and recorded. Supporting information such as air temperature, surface temperature, distance measurements, and identification data for each test point may be recorded either automatically or manually.

5.8 *Load Cell*—A load cell shall be used to measure the applied load of each impact. It shall be placed in a position to minimize the mass between the load cell and the surface. The load cell shall be positioned in such a way that it does not restrict the ability to obtain deflection measurements under the center of the load plate. The load cell shall be water resistant and shall be resistant to mechanical shocks from impacts during testing or traveling.

5.9 *LWD Size,* shall be small enough to be considered portable, i.e. not requiring a vehicle or trailer for transport.

6. Hazards

6.1 Injury can occur when elevating and dropping the falling weight. Some LWDs have relatively heavy falling weights, thus requiring the operator/recorder to keep his/her back straight, lifting with the leg muscles. Likewise, the operator/recorder should take care that his/her hands or extremities are not positioned beneath the lifted weight or loading plate, to avoid injury when the weight is falling.

7. Calibration

7.1 *Force-Generating Device*—Prior to load and deflection sensor calibration, precondition the device by dropping the weight at least five times and checking the relative difference in each peak load level. Peak load levels measured by the load cell shall not vary from each other more than ±3 %. If the variation exceeds this tolerance, the height of the drop, cleanliness of the track, along with any springs or rubber pads that are used to condition the load, shall be checked. Improperly operating parts shall be replaced or repaired prior to calibration to ensure that the horizontal and shear forces are minimized.

7.2 *Load Calibration Platform*—Follow the manufacturer's recommendations for load cell calibration since several types of these devices are commercially available.

7.3 *Deflection Sensors*—Calibrate sensors at least once per year or in accordance with the manufacturer's recommendations.

8. Signal Conditioning and Recorder System

8.1 All signal conditioning and recording equipment shall allow deflection measurements to be displayed and stored with a resolution of ±1 µm (±0.04 mils) or less.

8.2 The peak load and deflection measurements shall be recorded within a time period or measurement window of 60 ms or longer while still adhering to the precision and bias requirements shown in Section 10.

8.3 Peak load measurements shall be displayed and stored with a resolution of ±0.1 kN or less if using SI units, or ±10 lbf or less if using U.S. customary units, or an equivalent quantity if the load is expressed as mean stress depending on the plate radius.

9. Procedure

9.1 Position the instrument over the desired test point. The test surface shall be as clean and smooth as possible with loose granules and protruding material removed. For gravel surfaces, it is recommended that a thin layer of fine sand be placed over the test point. This helps in obtaining uniform contact between the load plate and the surface. A suitable rubber pad may be used for improving the load distribution.

9.2 Place the loading plate and the sensors to ensure they are resting on a firm and stable test surface.

9.3 Raise the falling weight to the desired height and allow it to fall freely.

9.4 Record the resulting peak surface deflection(s) and the peak load.

9.5 Perform at least two falling weight sequences (9.3) and compare the results. If the difference is greater than ±3 % for any sensor, note the variability in the report. Additional tests may be run at the same or at different load levels.

NOTE 3—It may be advantageous to use the first one or two drops for seating and use the subsequent drops for analysis.

10. Precision and Bias

10.1 *Equipment Precision*—The precision requirement for the deflection sensors is ±2 µm (0.08 mils). The precision requirement for the load cell is ±0.1 kN (22 lbf) or better.

10.2 *Equipment Bias*—The bias requirement for both the deflection sensors and the load cell is ±2 % or better.

10.3 *Between Device and Test Point Reproducibility*—The single operator, single equipment coefficient of variation of the test method for typical field conditions is 10 to 20 % for GM/GC/GP soils, 15 to 35 % for SW/SM/SP soils, and 40 to 60 % for ML/CL soils (see Practice D2487). The between device reproducibility of the test method for typical conditions is being determined and will be available on or before December 2009.

NOTE 4—Some LWD devices are designed and equipped such that the accuracy (precision and bias) as well as the load cell and sensor mounting requirements of this test method cannot be met. One or more of the following LWD features can lead to this conclusion: (*1*) the LWD is not equipped with a load-measuring device (load cell); (*2*) the LWD measures the deflection of the load plate rather than the deflection of the surface under test through a hole in the center of the load plate; (*3*) the LWD uses a sensor (velocity transducer or accelerometer) that is not linear down to zero Hz or is not processed using a Fourier transform analysis or equivalent.

NOTE 5—For the LWD devices referred to in Note 4, the approximate surface or composite modulus of the tested layer has been estimated to lie between 0.5 and 0.75 times the composite modulus calculated using an LWD device that meets the precision and bias requirements of this test method. A separate test method is being developed to cover this type of LWD device.

11. Keywords

11.1 deflection surveys; deflection testing; falling weight deflectometer (FWD); light weight deflectometer (LWD); impulse deflection testing; load-deflection testing; nondestructive testing (NDT); pavement deflection; pavement testing; pavement layer modulus; pavement layer stiffness; portable falling-weight deflectometer (PFWD)

ASTM E2835-21 Standard Test Method for Measuring Deflections Using a Portable Impulse Plate Load Test Device

Designation: E2835 – 21

Standard Test Method for Measuring Defections Using a Portable Impulse Plate Load Test Device[1]

This standard is issued under the fixed designation E2835; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method applies to measuring plate deflections using a Portable Impulse Plate Load Test device. The method covers the measurement of deflection of the load plate rather than the deflection of the surface of the pavement or foundation layers (see Note 1).

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1195/D1195M Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements

D4695 Guide for General Pavement Deflection Measurements

3. Summary of Test Method

3.1 This test method is a type of plate bearing test. The load is a force pulse generated by a falling mass dropped onto a spring assembly that transmits the load pulse to a plate resting on the material under test.

3.2 The mass is raised to a preset height and then dropped to deliver the desired force pulse. The device is calibrated to a preset drop height by the manufacturer. The preset drop height shall not be changed by the user.

3.3 The resulting plate deflection is measured using suitable instrumentation. Multiple drops from the same preset drop height may be performed at the same test location.

3.4 The peak plate deflection resulting from each drop at each location is recorded in micrometers or other unit of measure, as appropriate.

4. Signifcance and Use

4.1 This test method covers the determination of plate deflection resulting from the application of an impulse load. The deflection is measured at the center of the top of the load plate (see Note 1).

NOTE 1—If the load plate is in "perfectly uniform" contact with the unbound material under the plate, then deflection of the load plate should be equal to the deflection of the surface of the unbound material under test. However, with typical unbound materials a 100 % uniform contact can seldom be achieved. Accordingly, the test surface shall be as clean and smooth as possible with loose granules and protruding material removed. For gravel surfaces, it is recommended that a thin layer of fine sand be placed over the test point. For fine-grained materials, this will help in obtaining a reasonably uniform contact between the load plate and the surface. See 5.1 in Test Method D1195/D1195M.

4.2 Deflections may be either correlated directly to pavement performance or used to determine *in-situ* material characteristics of the pavement foundation layers. Some uses of the data include quality control and quality assurance of compacted layers, and for structural evaluation of load carrying capacity (see Note 2 and Guide D4695).

NOTE 2—The volume of the pavement foundation materials affected by the applied load is a function of the magnitude of the load, plate size and rigidity, loading rate, buffer stiffness, and the stiffness and shear strength of the pavement foundation materials. Therefore, care must be taken when analyzing the results because the data obtained by the Portable Impulse Plate Load Test may be obtained under substantially different conditions than when a heavy moving wheel load passes over the pavement surface after construction is complete.

[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.41 on Pavement Testing and Evaluation.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

5. Apparatus

5.1 *Instrumentation System,* conforming to the following general requirements.

5.2 *Instruments Exposed to the Elements,* operable in the temperature range from 0 °C to 50 °C (32 °F to 120 °F) and tolerant to relatively high humidity, rain and spray, and other adverse conditions such as dust, shock, and vibrations normally encountered.

5.3 *Force-Generating Device (falling mass),* capable of being raised, using a guide system, to a preset fixed height and dropped onto a steel-spring subassembly. Designed to operate with negligible friction or resistance.

5.4 *Force Pulse,* a half-sine or haversine-shaped load pulse, with a loading time between 10 and 30 msec, and reproducible within the requirements of 7.5.

5.5 *Load Plate,* shall be rigid and capable of transferring the impulse force to the surface. The stress distribution under the load plate depends on both load plate rigidity and material type, and therefore can be parabolic, inverse parabolic, or uniform **(1)**.[3]

5.6 *Deflection Sensor(s),* capable of measuring the maximum vertical plate movement. The deflection sensor or sensors shall be mounted so that the angular rotation is minimized with respect to its measuring plane at the maximum expected deflection. The number and spacing of the sensors is optional and will depend upon the purpose of the test and the material characteristics. Sensors may be of several types such as velocity transducers or accelerometers. The instrument shall be constructed to measure the vertical plate deflection at the center of the point of impact.

5.7 *Data Processing and Storage System,* displays and optionally records the deflection data.

5.8 *Portable Impulse Plate Load Test Device,* shall be small enough to be considered portable. Does not require a vehicle or trailer for transport.

6. Reagents and Materials

6.1 Adhere to the precision and bias requirements of this standard.

6.2 Display and store deflection measurements with a resolution of ±20 µm (±0.8 mils) or less.

6.3 Store deflection measurements for a period of 50 msec or greater to ensure that the peak deflection(s) are recorded.

7. Calibration

7.1 Calibrate the force-generating device and the deflection sensor(s) once per year.

7.2 Calibrate the force-generating device and the deflection sensor(s) using a measurement system independent of the Portable Impulse Plate Load Test device.

7.3 Execute calibration at an accredited laboratory using an approved calibration procedure **(2)**.

7.4 Verify deflection measurements after the independent calibration is complete (see Section 8).

7.5 *Force-Generating Device*—Calibrate the force-generating device prior to the deflection sensor calibration in accordance with manufacturer's recommendations and in consideration of the following requirements:

7.5.1 Precondition new spring assemblies with at least 100 drops before the calibration procedure is started. Start the calibration procedure no earlier than 1 h after preconditioning **(2)**.

7.5.2 Precondition all (both new and used) spring assemblies immediately prior to the calibration sequence with three drops of the falling mass.

7.5.3 Use a load cell rated from 20 to 50 kN **(2)**.

7.5.4 Test amplifier with a low-pass filter of at least the fourth order (critical frequency 200 Hz at 3 dB damping) with filter characteristics as presented by Butterworth **(2)**.

7.5.5 Measure and store the entire force record using an oscilloscope or other suitable measuring device with the appropriate resolution and storage, or a personal computer **(2)**.

7.5.6 Ensure the force pulse meets the requirements of this standard under Section 5.

7.5.7 Ensure that the reference load cell is uniformly supported by a rigid base (that is, a concrete foundation not less than 0.8 m (32 in.) in length, 0.8 m (32 in.) in width, and 0.5 m (20 in.) thick). The rigid base shall not generate any interfering vibrations as a result of the impact load **(2)**.

7.5.8 Clean the guide rod and ensure that it remains vertical to minimize friction.

7.5.9 Release the drop mass no less than ten times from the same drop height.

7.5.10 Adjust the drop height until the deviation of the mean force is within ±1 % of the desired force value. Additionally, ensure that the difference between the individually measured force values and the mean force does not exceed ±2 % (see Note 3).

7.5.11 Record each peak load level.

7.5.12 Permanently display the calibrated drop height on the device.

7.6 *Deflection Sensor*—Calibrate sensor(s) in accordance with the manufacturer's recommendations and in consideration of the following requirements.

7.6.1 Measure the peak load during deflection sensor calibration.

7.6.2 Check conformity of deflection measurements within at least the following three ranges:

7.6.2.1 ≥0.2500 mm and ≤0.4000 mm with a target value of 0.3 mm.

7.6.2.2 ≥0.4000 mm and ≤0.6000 mm with a target value of 0.5 mm.

7.6.2.3 >0.9000 mm with a target value of 1.4 mm.

7.6.3 For each deflection range, drop the falling mass no less than ten times from the drop height determined during calibration of the force-generating device.

7.6.4 Adjust the data processing and storage system and repeat calibration when the difference between the mean of the deflection measured by this unit and the deflection measured by the independent control unit is more than 0.02 mm (0.8 mils).

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

Ensure that the difference between individual measured values is less than or equal to 0.04 mm (1.6 mils) (**2**).

NOTE 3—Replace the spring assembly when the measured impact duration deviates ±2 msec or greater from the specified impact duration.

8. Verifcation Testing

8.1 Perform verification testing to establish the repeatability of deflection measurements under well-defined conditions when on-site measurements are not repeatable or are questionable (see Note 4).

8.2 Equipment requirements are as follows:

8.2.1 Rigid (that is, concrete) foundation as the testing platform.

8.2.2 Pads to allow deflection measurements in the ranges specified for the calibration procedure.

8.2.3 Pad dimensions no smaller than 1.5 times the load plate diameter.

8.2.4 Fully charged batteries.

8.3 Meet the following environmental requirements:

8.3.1 Complete verification testing at a temperature range from 16 °C to 22 °C (60 °F to 72 °F).

8.3.2 Allow sufficient time for the equipment to reach this specified temperature range.

8.4 Perform verification testing using the following procedure:

8.4.1 Mark test location on rigid foundation and test pad(s).

8.4.2 Place pad(s) on marked test location.

8.4.3 Place test device on marked test pad(s).

8.4.4 Perform nine mass drops using the specified procedure (see Section 3).

8.4.5 Record resulting peak deflection values.

8.4.6 Record supporting information such as air temperature, surface temperature, distance measurements, and other test identification data as needed.

8.5 Complete the following calculations (**2**) or similar analyses to ensure repeatability of deflection measurements:

8.5.1

$$S_{max} - S_{min} \leq 0.04\ mm\ (1.6\ mils) \quad (1)$$

where:

S_{max} = max(S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9),
S_{min} = min(S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9),
S_i = deflection measurements for drop i (where i = 1 to 9), mm,
S_{max} = maximum deflection measurement, mm, and
S_{min} = minimum deflection measurement, mm.

8.5.2

$$|S_{mean} - S_i| \leq 0.02\ mm\ (0.8\ mils)\ for\ each\ S_i \quad (2)$$

8.5.2.1

$$S_{mean} = \frac{\sum_{i=1}^{9} S_i}{9} \quad (3)$$

where:

S_i = deflection measurements for drop i (where i = 1 to 9), mm, and
S_{mean} = mean deflection for a set of nine verification test drops on the given pad configuration, mm.

8.5.3 $|S_i - S_{mean@calibration}| \leq$ 0.02 mm (0.8 mils) (see Note 5).

8.6 Repeat above procedure on remaining pad configurations.

8.7 Submit device for calibration when the conditions outlined in 8.5 are not met for any pad configuration.

NOTE 4—It may be beneficial to perform verification testing on newly purchased or recently calibrated devices to ensure the device is working properly prior to Portable Impulse Plate Load Test device commissioning. This would also provide a baseline to which later verification testing could be compared.

NOTE 5—This calculation is carried out if deflections during calibration were measured under the same conditions as the subsequent verification tests.

9. Hazards

9.1 Keep back straight and lift with leg muscles when elevating, dropping, and catching the mass.

9.2 Make sure that hands are not positioned beneath the elevated mass.

9.3 Secure load mass into the lower locked position prior to and during transportation between test locations.

10. Maintenance and Handling

10.1 Inspect equipment for necessary repairs (see Note 6).

10.2 Store test device in a dry place when not in use.

10.3 Protect the guide rod from contact with unbound materials.

10.4 Clean the force-generating device by removing any dirt with a dry cloth. Do not grease the guide rod since it is generally made of stainless steel.

10.5 Check the drop height regularly to ensure that the release mechanism has not moved from the preset height determined during calibration.

10.6 Maintain battery charge greater than 50 %.

NOTE 6—For some devices, ensure that the rubber bellow enclosing the spring assembly is providing a tight seal to protect the spring assembly from dust and damage.

11. Sample Selection

11.1 Perform unbound material test at the time of compaction and immediately after corrective actions.

11.2 Ensure pavement foundation layers are not frozen (**2**).

11.3 Perform test when the deflection measurements are greater than 0.2 mm (8 mils) and less than 3.0 mm (120 mils).

12. Site Selection and Preparation

12.1 Create a relatively smooth and level spot that will allow the guide rod to remain vertical and prevent translation of the load plate during testing.

12.2 Ensure the test area slope is less than 4 %.

12.3 Prepare a test area that is at least 1.5 times larger than the diameter of the loading plate.

12.4 Remove loose, dried, cracked, or uneven material prior to testing.

12.5 Perform tests by placing the load plate at a uniform depth. Ensure consistent plate test depths are maintained throughout the project for any given material type. The following test depths are recommended:

Material Type	Portable Impulse Plate Load Test Depth (see Note 7)
SW, SP, SW-SM, SW-SC, SP-SM, SPSC	≤ one-half lift thickness (see Note 8)
GW, GP, GW-GM, GW-GC, GP-GM, GP-GC, GM, GC, CL, ML, CH, MH, OL/OH, SM, SC	Compacted with Padfoot Roller:
	Bottom of deepest indentation of the padfoot penetration.
	Compacted with Smooth-Drum Roller:
	Compaction Surface (0 mm)

NOTE 7—The depth of influence is roughly 1 to 1.5 times the plate diameter. Consequently, deflection measurement obtained for a compacted lift with a thickness less than this influence depth will be a composite deflection measurement that is also influenced by the underlying lift.

NOTE 8—Complete test on the compaction surface for locations where the disturbance caused by preparation would cause the deflection measurements to increase and therefore become unrepresentative of the actual compacted condition.

13. Procedure

13.1 Position load plate on properly prepared test site (see Note 9).

13.2 Rotate load plate left and right 45° **(2)**.

13.3 Perform six falling mass drops. Use the first three drops for seating and the next three drops for analysis. Use the following procedure for each drop:

13.3.1 Raise falling mass to preset drop height and snap into the release mechanism.

13.3.2 Adjust guide rod to vertical.

13.3.3 Release falling mass and allow it to fall freely (see Note 10).

13.3.4 Catch falling mass after rebound as recommended by the manufacturer.

13.3.5 Raise and snap load mass into the release mechanism after rebound (see Note 11).

13.4 Record resulting peak deflection values.

13.5 Record supporting information such as air temperature, surface temperature, location, material type, and other identification information as needed.

13.6 Repeat deflection measurements at another location when conditions such as the following are present (see Note 12):

13.6.1 The load plate tilts more than 4 %.

13.6.2 The seating deflections differ from one another by more than ±10 %.

NOTE 9—Position the test device at a new test location when a faulty drop occurs. Testing cannot be repeated at the same location.

NOTE 10—Make sure the falling mass falls precisely from the calibration height **(2)**.

NOTE 11—Ensure the following for equipment constructed using a centering ball: (*1*) the guide rod is not removed from the centering ball, and (*2*) the load plate is not displaced during testing **(2)**.

NOTE 12—Additional compaction may be necessary or the material may be too moist when these conditions are present.

14. Precision and Bias

14.1 *Equipment Precision*—The precision requirement for the deflection measurement of the load plate is ±40 µm (1.6 mils; see also 7.6.4).

14.2 *Equipment Bias*—The bias requirement for the deflection sensor is ±2 %. The bias of the force introduced into the test layer is in the range of ±2 % on a concrete surface (7.5.10). The bias of the force for other surfaces is dependent on the properties of the material under test or the measured plate deflection, or both.

14.3 *Between-Device and Test Point Reproducibility*—The between-device and test point reproducibility of this test method for typical conditions is being determined and will be published as soon as it becomes available (see Notes 13-15).

NOTE 13—A Light Weight Deflectometer device with a load cell and where surface deflections are measured through a hole in the center of the load plate is designed such that the test results obtained may be appreciably different from a Portable Impulse Plate Load Test device without a load cell and where load plate deflections are measured.

NOTE 14—For Light Weight Deflectometer devices referred to in Note 13, the approximate surface or composite modulus that results from tests conducted on unbound materials has been estimated to lie between 1.4 and 2.0 times the composite modulus calculated using a Portable Impulse Plate Load Test device without a load cell and where plate deflections are measured. The main reason for this rather large discrepancy is that by measuring the plate deflection, a "perfect" contact between the plate and the unbound surface under test is not possible. There will always be micro-unevenness of any unbound material; therefore, larger plate deflections will invariably result than the deflection of the (uneven) surface of the unbound material under test unless a material such as plaster-of-paris is placed between the load plate and the surface under test, and allowed to harden.

NOTE 15—The peak force values slowly decrease as the peak deflections of the test layer increase (for example, by approx. 8 % at 2 mm deflection re. Reference **(3)** (see Appendix B for granular materials; Appendix C for cohesive materials; see also Reference **(4)** (in German) for further details).

15. Keywords

15.1 deflection surveys; deflection test methods; deflection testing; dynamic plate load testing (DPLT); impulse deflection testing device; light drop weight tester (LDWT); light weight deflectometer (LWD); load-deflection testing; nondestructive testing (NDT); pavement deflection; pavement foundation layers; pavement layer modulus; pavement layer stiffness; portable falling weight deflectometer (PFWD); portable impulse plate load test; quality assurance

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(2) Dynamic Plate-Load Test with the Aid of the Light Drop-Weight Tester, Technical Test Code for Soil and Rock Mechanics in Road Construction. TB BF-StB Part B 8.3 German Road and Transport Research Association, Working Group for Foundation and Soils Engineering., March 2003, chairman Prof. Dr.-Ing. Kudla, Freiberg.

(3) European Committee for Standardization. Measuring Method for Dynamic Compactness and Bearing Capacity with SP-LFWD (Small Plate – Light Falling Weight Deflectometer. Ref. No. CWA 15846:2008. English Version. CEN Workshop Agreement. ICS 93.020. Brussels, 2008.

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Standard Method of Test for Laboratory Determination of Target Modulus Using Light-Weight Deflectometer (LWD) Drops on Compacted Proctor Mold & Standard Method of Test for Compaction Quality Control Using Light Weight Deflectometer (LWD)

5.1. Laboratory Determination of Target Modulus Using LWD Drops on Compacted Proctor Mold

Standard Method of Test for

Laboratory Determination of Target Modulus Using Light-Weight Deflectometer (LWD) Drops on Compacted Proctor Mold

AASHTO Designation: TP 123-01 (2017)

1. SCOPE

1.1. This test method describes the procedure to determine the target modulus (or deflection) required for compaction quality control of geomaterials using Light Weight Deflectometer (LWD) drops on a compacted Proctor mold in the laboratory.

1.2. The same LWD type in terms of brand name, buffer stiffness, and deflection measurement location (on top of the plate or on top of the soil layer) used for the laboratory target modulus testing must be used during the field testing. This is to eliminate differences between measurements from different devices.

1.3. This procedure shall be performed in the laboratory on representative soil samples before the field compaction operations.

1.4. Gradation, moisture content inconsistency, and surface texture on the mold can affect the material moduli results.

1.5. The target surface modulus values can be compared to the field measured modulus in accordance with the TP 456-01 specification for compaction quality control/quality assurance purposes.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 265, Laboratory Determination of Moisture Content of Soils

- T 248, Method of Test for Reducing Samples of Aggregate to Testing Size
- TP 456-01, Compaction Quality Control Using Light Weight Deflectometer

2.2. *ASTM Standards*:

- E 2583-07, Measuring Deflections with a Light Weight Deflectometer (LWD)
- E 2835-11, Measuring Deflections using a Portable Impulse Plate Load Test Device
- D 3665-12, Standard Practice for Random Sampling of Construction Materials

3. APPARATUS

3.1. *Mold*— Solid-wall, metal cylinders with dimensions and specification conforming to Section 3.1 of T 99 or T 180. Only 152.4-mm (6-in.) diameter molds conforming to Section 3.1.2 T 99 or T 180 shall be used.

3.2. *Rammer*—A metal rammer conforming to Section 3.2 of T 99 for standard compaction energy or Section 3.2 of T 180 for modified compaction energy.

3.3. *LWD*—

3.3.1 The LWD testing apparatus should conform to the general requirements of Section 5 of either ASTM E 2583 for LWDs with load cells or ASTM E 2835 for LWDs without load cells.

3.3.2 The signal conditioning and recording of the LWD testing apparatus should conform to either Sections 8 of ASTM E 2583 for LWDs with load cells or Section 6 of ASTM E 2835 for LWDs without load cells.

3.3.3 The LWD testing apparatus should be regularly calibrated and verified according to the requirements of Sections 7 of ASTM E 2583 for LWDs with load cells or Sections 7 and 8 of ASTM E 2835 for LWDs without load cells.

3.3.4 The precision and bias of the LWD testing apparatus shall conform to Sections 10.1-10.2 of ASTM E 2583 for LWDs with load cells or Sections 14.1-14.2 of ASTM E 2835 for LWDs without load cells.

3.4. *Miscellaneous Equipment*— Balances and scales, drying oven, straightedge, sieves, mixing tools, and containers conforming to the requirements of Sections 3.4 through 3.9 in T 99 or T 180. A sample splitter or a similar tool conforming to the requirements of T 248.

4. PROCEDURE

4.1. This test is to be conducted as an add-on to the Proctor method of moisture-density relations of soils. Refer to T 99 or T 180, method B or D for the compaction of the specimen with three to five different moisture contents. Below is a highlight of the steps and cautions that should be taken:

4.1.1 Take a sample of approximately 40 kg (~90 lb) required for compaction of the Proctor molds from the construction material according to ASTM D 3665.

4.1.2. Separate an appropriate quantity of about 7 kg (~15 lb) or more from the representative soil for the compaction of one mold according to T 248.
Note 1—Exclude oversize particle if the total retaining is less than 10% on the largest sieve size.

4.1.3. Use standard compaction energy according to methods B or D of T 99 or modified compaction energy of T 180 to compact the specimen. Moisture content of the specimen can be selected roughly four percentage points below the material optimum moisture content based on experience, then added until the compaction curve is achieved (optional).
Note 2—Spread a uniform thickness including particles from all gradations in each layer.
Note 3—Avoid compacting and testing on a too damp soil where permanent deformation is observed after dropping the weight or excessive water is drained from the mold during the testing.

4.2. Rest the mold on a stable solid foundation or concrete floor. Carefully place the LWD with a 150-mm (5.905-in.) diameter loading plate on top of the mold and rotate approximately 45° back and forth to seat the plate. Any lateral movement of the plate with successive drops should be minimized.
Note 4—The diameter of the LWD plate is almost equal to mold diameter, so the plate should clear the rim of the mold (Figure 1, Appendix).
Note 5—A collar can be attached after trimming the compacted surface to help keep the LWD loading plate in place.

4.3. Hold the LWD rod vertical and conduct six drops at each drop height; Three seating drops followed by three measurement drops by raising the falling weight to each reduced drop height, then allowing the weight to fall freely without lateral movements. Start from the lowest drop height, then increase the height. Refer to ASTM E 2583, ASTM E 2853, and the LWD device manuals from the manufacturer for further instruction.
Note 6—Drops from reduced heights are used to monitor the stress dependency of material and permit interpolation/ extrapolation to the field plate pressure. Table 1 in the Appendix recommends drop heights for Zorn, Dynatest, and Olson LWDs with standard 10 kg (22 lb) drop weights.
Note 7— The generated force by the drop should deliver a half-sine or haversine shaped load with pulse duration of between 20 and 40 msecs for the devices with load cells (Section 5.3, ASTM E 2583) and between 10 and 30 msecs for devices without load cells (Section 5.4, ASTM E 2835). The load pulse duration depends on the soil stiffness and can be adjusted by altering the LWD buffer stiffness, plate size, and drop mass weight.

4.4. Record the deflections and applied loads from each drop height and/or export these from the data storage system.

Note 8—In instances where the soil material is fragile in character and where the grain size distribution will be altered significantly by repeated compaction, a separate and new soil sample shall be used in each compaction test.

Note 9—Calculate and observe the coefficient of variation for the three measurement drops. Repeat the testing if the coefficient of variation is more than ten percent.

4.5. Remove the material from the mold, take representative samples immediately, and determine the moisture content in accordance with T 265 and record the results.

Note 10—Taking moisture samples from the mixing container is preferred in case water is drained from the bottom of the mold during the testing.

5. CALCULATION

5.1. Plot the moisture-density relationship and determine the optimum moisture content and maximum density following the procedures in Sections 12 and 13 of T 99 or T 180. Determine the acceptable moisture content (MC_{field}) range according to the agency requirements.

5.2. The modulus of the soil in the mold is derived from the theory of elasticity for a cylinder of elastic material with constrained lateral movement:

$$E = \left(1 - \frac{2v^2}{1-v}\right)\frac{4H}{\pi D^2}k \qquad (1)$$

where:

v = Poisson's ratio (refer to Appendix Table 2 for the suggested values),
H = height of the mold,
D = the diameter of the plate or mold,
k = soil stiffness $=F/\delta$ as measured by the LWD device,
F = average maximum applied load by the LWD during the three measurement drops, and
δ = average maximum deflection measured by the LWD during the three measurement drops.

5.3. Each drop height on the mold corresponds to an applied pressure (P_{mold}).

$$P_{mold} = \frac{F}{\pi\left(D/2\right)^2} \qquad (2)$$

Note 11— It is optional to normalize the applied pressure to the atmospheric pressure (Pa=101.325 kPa or 14.69 psi) for the analysis (P/Pa).

Note 12—For LWD devices that do not have a load cell (ASTM E 2835), the magnitude of the peak load for the lower drop heights is estimated as being proportional to the square root of the drop height. Alternatively, the load for LWD devices that do not have a load cell can be calibrated for reduced drop heights.

5.4. A two-variable quadratic regression analysis should be performed to find the regression coefficients for LWD modulus measured on the mold as a function of the moisture content (MC_{mold}) and plate pressure.

$$E = a_0 + a_1 \times MC_{mold} + a_2 \times MC_{mold}^2 + a_3 \times P_{mold} + a_4 \times P_{mold}^2 \quad (3)$$

where:

a_0, a_1, a_2, a_3, a_4 = regression coefficients.

5.5. The range of material target moduli values (E_{target}) shall be obtained by inputting the acceptable moisture content range from Section 5.1 and the field plate pressure into the regression equation.

$$E_{taregt} = a_0 + a_1 \times MC_{field} + a_2 \times MC_{field}^2 + a_3 \times P_{field} + a_4 \times P_{field}^2 \quad (4)$$

Note 13—Field plate pressure (P_{field}) varies depending on the plate size and drop weight and can be determined as follows:

$$P_{field} = \frac{F_{field}}{\pi\left(\frac{D_{field}}{2}\right)} \quad (5)$$

where:

F_{field} = applied load from the LWD in the field, and

D_{field} = the diameter of the LWD plate in the field.

5.6. The target modulus can be compared to the measured field modulus (E_{field}) to assess the compaction quality following TP 456-01 Section 5.

6. REPORT

6.1. The test report shall include the following:

- Acceptable moisture content range in percent to the nearest whole number.
- Maximum laboratory dry density value in kilograms per cubic meter to the nearest 10 kg/m^3 or in pounds per cubic foot to the nearest whole number.
- The LWD device type used in laboratory testing on Proctor mold, the drop weight and plate diameter.
- LWD device to be used in the field, drop weight and plate diameter.
- Material target modulus range for 200-mm (7.87-in.) and/or 300-mm (11.81-in.) LWD plate sizes.
- Any corrections made in the reported values and the reason for the corrections (e.g. oversized particles, excessive water drainage unstable LWD plate, and/or poor contact with the compacted soil in the mold).

6.2. The report sample that has been attached in the Appendix Section can be used as a template to record the lab testing data.

7. APPENDIX

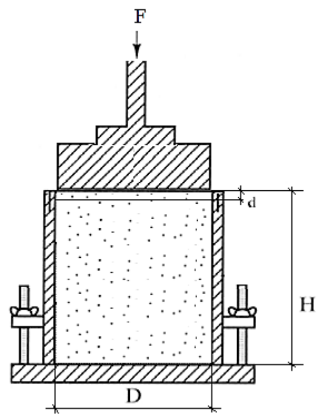


Figure 1— Schematic of LWD Testing on Proctor mold

Table 1—Suggested LWD Drop Heights on Proctor Mold for 10-kg Drop Weight

LWD type	Drop Heights (in.)					
Zorn	1	2	3	4	5	12.5
Dynatest	1	2	3	4	5	7
Olson	1	2	3	4	5	8.5

Table 2—Typical Values of Poisson's Ratio (from MEPDG)

Material	Range of values	Typical value
Untreated Granular Materials	0.30 - 0.40	0.35
Cement-Treated Granular Materials	0.10 - 0.20	0.15
Cement-Treated Fine-Grained Soils	0.15 - 0.35	0.25
Lime-Stabilized Materials	0.10 - 0.25	0.2
Loose Sand or Silty Sand	0.20 - 0.40	0.3
Dense Sand	0.30 - 0.45	0.35
Saturated Soft Clays	0.40 - 0.50	0.45
Silt	0.3 – 0.35	0.32
Clay (Unsaturated)	0.1 – 0.3	0.2
Sandy Clay	0.2 – 0.3	0.25
Coarse-grained Sand	0.15	0.15
Fine-grained Sand	0.25	0.25

Proctor Compaction and LWD on Mold Report

LWD Model (Plate Size): ___________ (   )
Material type: _____________________________
Operator: _________________________________
Date and Time: _________________________
Project Location: _______________________
Contract No: ____________________________

1. PROCTOR DATA	Mold No:	1	2	3	4	5
	1. Target Moisture Content [%]:					
	2. Compaction Energy (Std. or Mod. Proctor):					
	3. Weight of Mold:					
	4. Weight of Mold + Compacted Wet Soil:					
	5. Average %MC (from table 3):					
	6. Dry Density of the Mold:					

Poisson's Ratio:

2. LWD FILE NAME	Mold No:	1	2	3	4	5
	Drop Height #1:					
	Drop Height #2:					
	Drop Height #3:					
	Drop Height #4:					
	Drop Height #5					
	Drop Height #6:					

3. MOISTURE DATA	Mold No		Wt. of Container	Wt. Container +Wet Soil	Wt. Container +Dry Soil	MC [%]
	1	Sample 1				
		Sample 2				
		Sample 3				
	2	Sample 1				
		Sample 2				
		Sample 3				
	3	Sample 1				
		Sample 2				
		Sample 3				
	4	Sample 1				
		Sample 2				
		Sample 3				
	5	Sample 1				
		Sample 2				
		Sample 3				

4. REPORT VALUES				
	LWD Model:			
	Assumed Poisson's Ratio:			
	Maximum Dry Density:			
	Acceptable %Water Content:			
	E_{target}:			

5.2. Compaction Quality Control Using Light Weight Deflectometer (LWD)

Standard Method of Test for

Compaction Quality Control Using Light Weight Deflectometer (LWD)

AASHTO Designation: TP 456-01 (2017)

1. SCOPE

1.1. This specification describes the procedure to assure the compaction quality of a road base or subgrade by comparing the field surface moduli to the laboratory determined target moduli using a Light Weight Deflectometer (LWD).

1.2. The same LWD type in terms of brand name, buffer stiffness, and deflection measurement location (on top of the plate or on top of the soil layer) used for the laboratory target modulus testing must be used during the field testing. This is to eliminate differences between measurements from different devices.

1.3. This procedure shall be performed within two hours after compaction to eliminate the effect of surface drying on the modulus values. This method does not count for post compaction wetting/drying and environmental effects.

1.4. An appropriate in situ method of soil moisture content measurement shall be used to rapidly determine the moisture content at the time of compaction and testing.

1.5. The target modulus should be corrected for a base or subbase layer of finite thickness compacted over subgrade.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- T 265, Laboratory Determination of Moisture Content of Soils
- R 9-05, Acceptance Sampling Plans for Highway Construction
- AASHTO Guide for the Design of Pavement Structures (1993)
- TP 123-01, Laboratory Determination of Target Modulus Using Light-Weight Deflectometer Drops on Compacted Proctor Mold

2.2. *ASTM Standards*:
- E 2583-07, Measuring Deflections with a Light Weight Deflectometer (LWD)
- E 2835-11, Measuring Deflections using a Portable Impulse Plate Load Test

Device

- D 3665-12, Standard Practice for Random Sampling of Construction Materials
- D 4643-00, Determination of Water (Moisture) Content of Soil by the Microwave Oven Heating
- D 4944-11, Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester
- D 4959-16, Determination of Water Content of Soil by Direct Heating

3. APPARATUS

3.1. *LWD*—

3.1.1 The LWD testing apparatus should conform to the general requirements of Section 5 of either ASTM E 2583 for LWDs with load cells or ASTM E 2835 for LWDs without load cells.

3.1.2 The signal conditioning and recording of the LWD testing apparatus should conform to either Sections 8 of ASTM E 2583 for LWDs with load cells or Section 6 of ASTM E 2835 for LWDs without load cells.

3.1.3 The LWD testing apparatus should be regularly calibrated and verified according to the requirements of Sections 7 of ASTM E 2583 for LWDs with load cells or Sections 7 and 8 of ASTM E 2835 for LWDs without load cells.

3.1.4 The precision and bias of the LWD testing apparatus shall conform to Sections 10.1-10.2 of ASTM E 2583 for LWDs with load cells or Sections 14.1-14.2 of ASTM E 2835 for LWDs without load cells.

3.2. *Moisture Content Testing*—An appropriate in situ method of soil moisture (water) content measurement shall be used to rapidly determine the moisture content at the time of compaction and testing. Example equipment for accomplishing this include the Ohaus Moisture Analyzer, Microwave Oven (ASTM D 4643), Field Stove (ASTM D 4959), Speedy Moisture Tester (ASTM D 4944), etc. and a portable power generator if deemed necessary.

3.3. *Miscellaneous Equipment*—

- A small square shovel or similar tool to level the testing surface.
- A soil sampler and sealed containers/bags to collect the moisture content samples.
- Marking spray to designate the LWD testing locations.
- Tape measure or measuring wheel.

4. PROCEDURE

4.1. Determine the LWD model, acceptable moisture content range and corresponding E_{target}, and assumed Poisson's ratio following the TP 123-01 test method in

advance of the compaction operation. Input the Poisson's ratio and the appropriate shape factor from Table 1 into the LWD device.
Note 1—Different LWDs report different moduli values. The same LWD type in terms of manufacturer, model, and buffer stiffness used for the laboratory target modulus testing must be used for the field testing.

4.2. Control of moisture content is a critical factor in attaining proper compaction of geomaterials.

4.2.1. Take at least three random moisture samples per sublot per ASTM D 3665 or similar. One sample shall be taken during placing/spreading of each lift and two samples shall be taken immediately after compaction.

4.2.2. Use the moisture content testing equipment appropriate for field use (Section 3.2) to measure the moisture content of each sample.

4.2.3. The average moisture content shall comply the acceptance requirement in Section 7.1.

4.2. Identify random LWD testing locations per ASTM D 3665 or similar. The minimum testing frequency is specified in Section 6.2. Mark and label the LWD testing locations.
Note 2—LWD testing shall be performed within two hours of compaction to avoid moisture loss. The average moisture content of the two samples at the time of testing may not deviate more than 2 percentage points from the sample obtained at the time of the layer placement.

4.3. Record the LWD testing locations and any noteworthy remarks.

4.4. Carefully clear and level the area underneath the LWD plate without any disturbance to the compacted surface. Remove loose oversized rocks. In case of open graded base material, a thin layer of sand can be used to fill in the gaps to provide full contact with the plate.

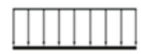
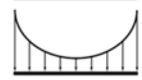
4.5. Position the load plate and rotate left and right approximately 45 degrees to achieve intimate contact between the plate and soil surface.

4.6. Perform 6 drops following the manufacturer's instructions and in general accordance with ASTM E 2583 for LWDs with load cells and ASTM E 2835 for LWDs without load cells. The first three drops are for the seating and the second three drops are for modulus measurement. Record the reported device data storage file names and moduli values (optional).
Note 3—When testing a base layer of finite thickness, it is necessary to perform LWD testing on the surface of the underlying soil before the base material placement. These tests should be performed at the same locations (determined by Section 4.2) on the same day that the base is placed. Then perform the LWD

testing on top of the compacted base layer and correct the target modulus as described in Section 5.3.

Note 4—During LWD testing, pay attention to the deflections/modulus for each drop. Repeat the testing at an adjacent location in case an outlier deflection/modulus data captured for a drop.

Table 1—Stress Distribution Factor for Different Types of Soil

Soil type	Factor (A)	Stress distribution factor
Mixed soil (uniform)	2	
Granular material (parabolic)	8/3	
Cohesive (inverse-parabolic)	π/2	

5. CALCULATION

5.1. The field modulus is calculated using the half space Boussinesq equation assuming the test media to be a linear elastic, isotropic, and homogeneous semi-infinite continuum:

$$E_{field} = \frac{2k(1-\nu^2)}{Ad} \qquad (1)$$

E_{field} = field modulus,
k = average soil stiffness $=F/\delta$ as measured by LWD device,
F = maximum load applied by the LWD device,
δ = maximum deflection measured by the LWD device,
A = stress distribution factor obtained from Table 1,
ν = Poisson's ratio obtained from Section 4.1, and
d = LWD plate radius.

5.2. *Target Modulus for Subgrade and Embankment*—The subgrade layer is assumed to be infinite in extent in the horizontal and downward vertical directions. So, the target modulus is equivalent to the material target modulus at a given moisture content as obtained from TP 123-01.

5.3. *Target Surface Modulus for Base Courses*—According to *AASHTO Guide for the Design of Pavement Structures (AGDPS)*, the total surface deflection directly under the circular load (LWD plate) is the summation of deformation occurring in the top and bottom layer (Figure 1). When evaluating a base layer of finite thickness, the target modulus obtained from Section 4.1 should be corrected using Equation 2 or Figure 2 in the Appendix. The corrected E_{target} is then used to compare to E_{field}.

$$E_{target-corr} = 1 \Big/ \left\{ \frac{1}{E_2\left[\sqrt{1+\left(\frac{h}{d}\sqrt[3]{\frac{E_1}{E_2}}\right)}\right]} + \frac{\left[1-\frac{1}{\sqrt{1+\left(\frac{h}{d}\right)^2}}\right]}{E_1} \right\} \qquad \textbf{(2)}$$

$E_{target-corr}$ = corrected target modulus for the base material,
E_2 = modulus of the foundation (subgrade, or subbase plus subgrade) measured by the LWD before base placement according to Section 4.6,
E_1 = target modulus for the base material from the TP 123-01 (E_{target} from Section 4.1),
h = base layer thickness, and
d = LWD plate radius used during field testing.

5.4. Calculate the ratio E_{field}/E_{target} for subgrade and embankment materials or $E_{field}/E_{target-corr}$ for finite thickness base layers.

6. SAMPLING FREQUENCY

6.1. In order to assure that LWD testing is performed over the entire lot and not concentrated in one area, stratified random sampling using random locations within sublots is recommended according to ASTM D 3665.

6.2. The minimum frequency of LWD test shall be as outlined herein. Additional testing shall be performed if deemed necessary by the Engineer.

- For subgrade, base, and subbase compaction: Divide each lane mile into 4 sublots per lift and perform a minimum of 10 LWD tests per sublot at random locations.
- For road embankment material that is 1 ft or more below the top of subgrade: Divide each lane mile into 4 sublots per lift and perform a minimum of 5 LWD tests per sublot at random locations.

7. ACCEPTANCE

7.1. The average moisture content of the samples collected immediately after compaction shall fall within the acceptable moisture content range as determined by the TP 456-01 specification and agency policy.

7.2. The field to target ratios calculated per Section 5.4 shall be evaluated for acceptance using the percentage of material within specification limits method (PWL) following R 9-05 specification. The preliminary recommendations for lower specification limit shall be 0.5 for the devices that comply with ASTM E 2583 (LWDs with load cells) and 0.8 for the devices complying ASTM E 2835 (LWDs without load cells) or other values as determined by the agencies.

7.3. The lot shall be rejected once a "large" percentage is outside the specification limit according to R 9 Section 8.12.7. Local agencies may want to perform additional implementation studies to refine the lower specification limit and/or the acceptable PWL. Typically, the lot may be rejected if PWL is less than 50%.

7.4. Appropriate remedial procedures shall be adopted for the materials that do not meet the acceptance criteria. These materials shall be re-tested for acceptance after corrections.

8. REPORT

8.1. The test report shall include the following:

- Project location and weather description.
- Material type, lift number, layer thickness, and construction timeline.
- Moisture content measurement device, number of samples, time and locations of measurement, percent moisture content.
- LWD model used during field testing, plate size, drop height, and drop weight.
- Recorded test area coordinates and numbered test locations.
- Target modulus correction for finite layered thickness and LWD plate radius.
- Test location identification and measured LWD moduli or device file name at each location.

8.2. The sample report sample included in the Appendix can be used as a template for the test report.

9. SAFETY

9.1. Carefully follow the manufacturer's instructions on the LWD device assembly and operation. To prevent any damage to the device, make sure all the parts are firmly attached before dropping the load in the field.

9.2. Keep the back straight and lift the weight with leg muscles to avoid back strain.

9.3 Always secure the safety interlock when pausing the test or transporting the LWD to new locations.

9.4. Avoid placing the hands below the elevated drop weight.

10. APPENDIX

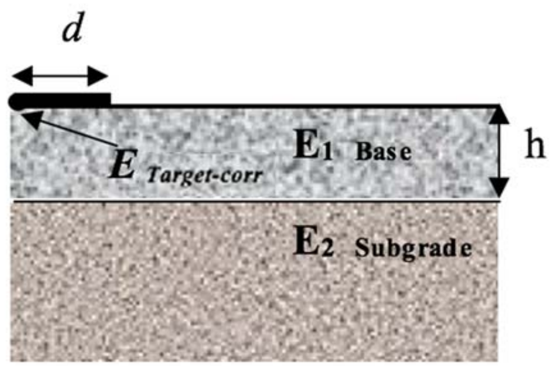


Figure 1—Schematic of the two-layer system of subgrade with modulus E_2 overlain by base with modulus E_1

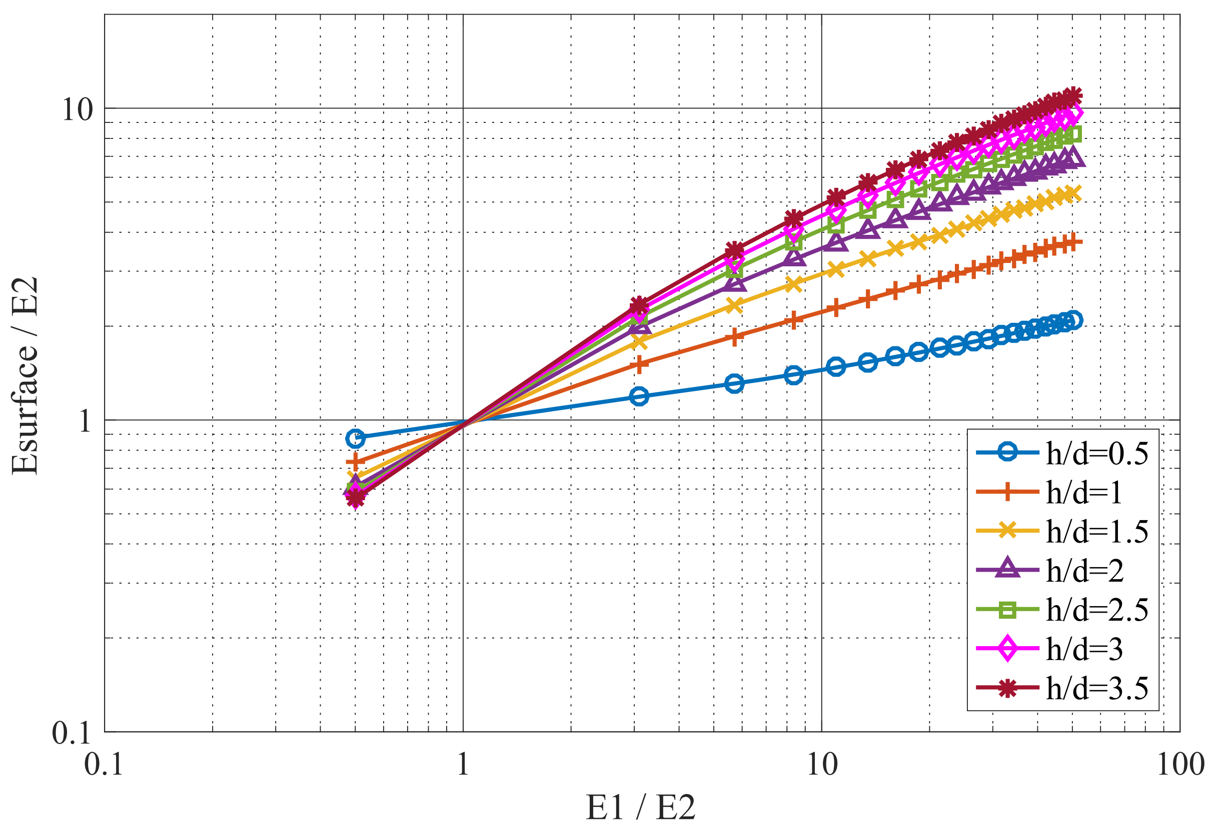


Figure 2— Surface Modulus Correction for Testing on Compacted Base Layer of Finite Thickness (h = base layer thickness, d = LWD plate radius used during field testing)

Field QC/QA using LWD Report

Date and Time: ________________________ **Operator:** ________________________________

Material type: ________________________ **Project Location:** ______________________

Weather condition		**COMPACTION TIMELINE**	
LWD Model			
LWD plate size			
LWD drop height			
LWD drop weight			

MC testing device:			
Sample	**Location**	**Drying duration**	**%MC**
1			
2			
3			

Lift No.:			**Lift thickness:**	
Poison's ratio:			**Shape factor (A):**	
LWD TESTING DATA	**Station/Logmile**	**Centerline offset**	**LWD file name**	**Field observation and remarks**

Appendix B – Alaska LWD Standards

ATM 310 Relative LWD Deflection of Embankment Materials by the Control Strip Method

Modifications to the DOT&PF Standard Specifications for Highway Construction

DRAFT ATM Laboratory Determination of Target Modulus for Lightweight Deflectometer (LWD)

ATM 310 Relative LWD Deflection of Embankment Materials by the Control Strip Method

ATM 310 Relative LWD Deflection of Embankment Materials by the Control Strip Method

1. Scope

This method describes a procedure for utilizing a Lightweight Deflectometer (LWD) for compaction quality assurance by the control strip method. This test method is applicable to unbound soils and aggregates.

LWD Target Values (LWD-TV) established with this method are device specific and must be determined for each device used in acceptance testing of the material. Assurance checks should be of the LWD-TVs determined during this procedure. The moisture content values should be determined using an engineer-approved method to measure in-situ soil moisture content.

2. Significance and Use

LWD devices provide an alternative to traditional quality assurance (QA) acceptance testing methods such as nuclear moisture density gauges. LWD devices provide a lower cost and logistically easier method to verify compaction efforts. This method describes a procedure to determine the LWD-TV for use when acceptance testing will be completed using an LWD device.

3. Apparatus

- LWD meeting the requirements of ASTM D2583 or D2835
- Compaction equipment that meets the requirements of the contract and of sufficient size and compaction energy to compact the material
- Equipment to measure in-situ moisture content per AASHTO T 255 or T 265

4. Site Selection and Preparation

The Engineer will designate the location of the control strip. A representative lift of the material being evaluated will be placed and prepared for compaction. For control strip dimensions, see Table 1 below.

Table 1: LWD Control Strip Dimensions

Embankment	Length	Width	Fill Thickness
Roadbed Embankment Soil and Base	≥ 200 feet	12 feet	Equal to the planned layer thickness for base & 12 inch maximum for embankment
Miscellaneous trench, culvert or other tapered construction	≥ 60 feet	Planned width	

Level the test area so that the entire surface area of the load plate is in contact with the material. Remove loose material, protruding rocks, and other debris from an area 1.5 times larger than the loading plate. Fill uneven spots with fine to medium sand if necessary.

5. Procedure – Control Strip Method

1. Construct a control strip to determine the LWD-TV for each type or source of material. Construct a new control strip when there is a new source, an observable variation in material properties, the moisture content of the material varies more than 2 percent from the control strip moisture content, or as requested by the Engineer. Perform tests when the material is within the moisture content range specified in the contract.
2. Save samples of material from each control strip for later comparison to compacted material. The number of samples will be determined by the Engineer.
3. The Engineer will select test locations. Control strip test locations should be a minimum of 20 feet apart for base and embankment and a minimum of 6 feet apart for trenches. For road embankment and base, there should be 3 test locations per pass and for trenches there should be 2 test locations per pass. Choose the testing locations with care and prepare the area by ensuring the surface is flat, fill any voids with fine to medium sand if necessary, and remove any surface debris.
4. Mark the locations so as not to be lost during compaction of the control strip. Mark the side of the strip with stakes or surveyors tape, or mark with paint beside the location on the control strip or use other engineer-approved method.
5. Begin test curve determination at least 2 roller passes before you believe desired compaction will be reached. Take tests with a LWD device at each of the designated locations in the control strip. Perform tests in accordance with the LWD manufacturer's recommendations.
6. Record deflection measurements from measurement drops on the data collection form. Record any additional supporting information such as location measurements and identification data in field book or reporting forms.
7. Obtain moisture content on a sample collected 2 to 4 inches below LWD test surface using AASHTO T 255 or T 265. Record the moisture content information on the data collection form.
8. Once LWD test curve determination has begun, determine initial deflection by averaging the deflections of the three selected test locations. After each subsequent pass, perform an LWD and moisture content test at each location. Record and average the results to produce the deflection value of that pass.
9. Continue compaction and LWD testing cycle until the moisture content is within the acceptable range and the average deflection for three consecutive passes, does not change with additional compaction.
10. Select ten random locations within the control strip, perform three measurement drops at each location, and average those three deflections to calculate the deflection at each location. Average the results from these ten locations to determine the LWD-TV for this material.
11. Obtain a new LWD-TV if the material changes, more than 20 percent of the measured deflections are ≤ 0.60 x (LWD-TV) and/or failing results consistently occur with adequate compaction effort and moisture conditions.

6. Calculations

Calculate the LWD-TV as follows:

$$LWD - TV = \frac{(D_1 + D_2 + D_3 + D_4 + D_5 + D_6 + D_7 + D_8 + D_9 + D_{10})}{10}$$

Where:
LWD-TV = Deflection Target Value (mm)
D_n = Average Deflection for random test location n (mm)

7. Acceptance Testing

The average of the three measurement drops per location in a LWD test is the Deflection Test Measurement (DTM) and is used as the acceptance criteria when compared to the LWD-TV. See project contract for detailed acceptance criteria.

8. Report

Include the following on the test report:

- Material type, lift number, and lift thickness.
- Acceptable moisture content range.
- Moisture content measuring device, test location, test number, in-situ moisture content.
- Assumed Poisson Ratio from the table provided in the specifications.
- Target deflection values (LWD-TV).
- The LWD device brand & model.
- LWD test number and the DTM.
- Identifying information – project number, lab sample number, technician, date, etc.
- Any additional notes such as excess moisture, weather, etc.

Modifications to the DOT&PF Standard Specifications for Highway Construction

SECTION 203
EXCAVATION AND EMBANKMENT

Standard Modification

Replace Section 203-3.04 with the following:

203-3.04 COMPACTION WITH MOISTURE AND DENSITY CONTROL. Compaction shall be controlled by Method 1 (nuclear) or Method 2 (light weight deflectometer (LWD)).

Method 1: The maximum density and optimum moisture will be determined by ATM 207 or ATM 212.

Adjust the moisture content of the embankment material to within 2 percent of the optimum moisture content and compact each layer to not less than 95 percent of the maximum density. Acceptance densities will be determined by ATM 213.

Method 2: The target deflection (LWD-TV) will be determined by ATM 310.

Adjust the moisture content of the embankment material to meet Table 203-1 or as directed by the Engineer.

TABLE 203-1
TARGET MOISTURE CONTENT

Material	Moisture Content
Selected Material, Type A	6-9%
Base Course, Gradation D-1	6-8%
Surface Course, Gradation E-1	5-8%
Subbase	5-15%

Compact each layer to achieve a Deflection Test Measurement less than or equal to 1.2 times the LWD-TV. Acceptance deflections will be determined by ATM 310.

203-5.05 BASIS OF PAYMENT. Add the following to the list of subsidiary work

10. Control strip construction and testing to determine the LWD-TV value.

SECTION 205
EXCAVATION AND FILL FOR MAJOR STRUCTURES

Standard Modification

Replace Section 205-3.05 with the following:

205-3.05 COMPACTION. Compact material in conformance with the following, using moisture and density control unless the Engineer determines that such controls are not feasible.

1. Compaction With Moisture and Density Control. Control compaction by Method 1 (nuclear) or Method 2 (LWD).

   Method 1: The maximum density and optimum moisture will be determined by ATM 207 or ATM 212.

   Water or aerate as necessary to provide the approximate optimum moisture content for compaction. Compact each layer to not less than 98 percent of the maximum density. Acceptance densities will be determined by ATM 213.

   Method 2: The target deflection (LWD-TV) will be determined by ATM 310.

   Adjust the moisture content of the material to the target range determined during the Control Strip testing. Compact each layer until the measured deflection is less than or equal to 1.2 times the LWD-TV. Acceptance deflections will be determined by ATM 310.

2. Compaction Without Moisture and Density Control. Compact each layer before the next layer is placed. Compact to the satisfaction of the Engineer.

   Do not place additional material cover until the Engineer has determined the required compaction is obtained.

SECTION 301
AGGREGATE BASE AND SURFACE COURSE

Standard Modification

Replace Section 301-3.03 with the following:

301-3.03 SHAPING AND COMPACTION. Control compaction by Method 1 (nuclear) or Method 2 (LWD).

Method 1: The maximum density and optimum moisture will be determined by ATM 207 or ATM 212.

Spread and shape the material to the required grade and section. Water or aerate as necessary to provide the approximate optimum moisture content for compaction. Compact each layer to a density of not less than 98 percent of the maximum density. Acceptance densities will be determined by ATM 213.

Method 2: The target deflection (LWD-TV) will be determined by ATM 310.

Adjust the moisture content of the material to the target range determined during the Control Strip testing. Compact each layer until the measured deflection is less than or equal to 1.2 times the LWD-TV. Acceptance deflections will be determined by ATM 310.

Maintain the surface of each layer during the compaction operations to provide a uniform texture of firmly keyed aggregates.

The finished surface will be tested using a 10-foot straightedge at selected locations. Limit surface deviations to 3/8 inch, as measured from the testing edge of the straightedge between two contacts with the surface.

SECTION 308
CRUSHED ASPHALT BASE COURSE

Standard Modification

Replace Section 308-3.04 with the following:

308-3.04 COMPACTION AND COMPACTION EQUIPMENT. Control compaction by Method 1 (nuclear) or Method 2 (LWD).

> Method 1: The Engineer will use ATM 412 to determine the density standard. Make each control strip at least 12 feet by 300 feet. Compact the remainder of the project to not less than 98 percent of the density standard, in accordance with ATM 411. The Engineer will designate the location of the test strips.
>
> Method 2: The target deflection (LWD-TV) will be determined by ATM 310. Adjust the moisture content of the material to the target range determined during the Control Strip testing. Compact each layer until the measured deflection is less than or equal to 1.2 times the LWD-TV. Acceptance deflections will be determined by ATM 310.

Compact the base course using vibratory compactors, applying a minimum dynamic force of 50,000 pounds per vibration at a minimum frequency of 1,000 vibrations per minute. Adjust working speed in order to apply 8 to 12 impacts per foot. In areas inaccessible to rollers, use mechanical tampers until thoroughly compacted.

DRAFT ATM Laboratory Determination of Target Modulus for Lightweight Deflectometer (LWD)

DRAFT ATM Laboratory Determination of Target Modulus for Lightweight Deflectometer (LWD)

1. Scope

This procedure covers the laboratory determination of target modulus using LWD drops on a compacted proctor mold in accordance with AASHTO TP 123-01. This test method describes the procedure to determine target modulus required for compaction quality control from LWD drops on a compacted proctor mold. The same LWD type used for the laboratory target modulus should be used for the field testing. Variation in test results can be caused by:

- Gradation inconsistency
- Moisture content inconsistency

The moisture-density relations of soils testing should follow the procedures outlined in ATM 207, methods B or D. The target modulus values and the field modulus values can be compared in accordance with AASHTO TP 456-01 specification for compaction quality assurances purposes.

2. Apparatus

See ATM 207 for apparatus required for the moisture – density relations of soil. See ATM 202 for apparatus required for the laboratory determination of moisture content of soils.

- LWD – meeting the requirements of ASTM 2583
    - Load Plate – a metal disk capable of evenly distributing the impulse load on the surface. Pavement deflection measurements should be taken at the center point of impact, through a hole in the plate.
    - Force Generating Device – 10 kg falling weight operating with negligible friction or resistance
    - Deflection Sensor(s) – capable of measuring the maximum vertical movement and mounted in a manner that minimizes the angular rotation
    - Load Cell – capable of measuring the applied load of each impact and placed in a position that does not impede the ability of the device to measure deflection
    - Data Collection Device – capable of recording, displaying, and storing the load and deflection data

3. Sampling and Sample Preparation

Obtain a representative test sample in accordance with ASTM D 3665 and reduce the sample size if needed in accordance with AASHTO T 248.

4. Procedure

Conduct proctor test according to the usual test method, ATM 207, method B or D. After compaction at each moisture content, the following steps should be taken:

1. Place mold on stable surface (concrete floor, etc) and place the LWD with the 150 mm load plate on top of the mold. Seat the plate to minimize lateral movement of the LWD and ensure that the LWD is not resting on the proctor mold.
    a. Make sure that the geophone lock is used at the lab and in the field for compaction testing.
2. Hold the LWD vertical and conduct six drops at each drop height. The first three drops are seating drops and the last three are the measurement drops. The recommended drop heights for a Dynatest LWD are as follows: 1 in, 2 in, 3 in, 4 in, 5 in, and 7 in. Start at the lowest drop height and increase the drop height as appropriate.
3. Record the deflections and applied loads from each drop height on the laboratory reporting form and make sure they are named and saved appropriately in the program on the data collection device.
4. Take samples for moisture content in accordance with ATM 202.

5. Calculations

Plot the moisture-density relationship and determine the optimum moisture content and maximum density.

The modulus of the soil in the mold is determined by the following equation:

$$E = \left(1 - \frac{2v^2}{1-v}\right) * \frac{4H}{\pi D^2} * k$$

Where:

V = Poisson's Ratio
H = height of mold
D = diameter of the plate or mold
K = soil stiffness = F/S (measured by LWD)
F = average maximum applied load by the LWD during the 3 measurement drops
S = average maximum deflection measured by the LWD during the 3 measurement drops

6. Each drop height corresponds to an applied pressure (P_{mold}) as determined by the following equation:

$$P_{mold} = \frac{F}{\pi (^{D}/_{2})^2}$$

7. A regression analysis needs to be performed to obtain the regression coefficients for the LWD modulus measured on the mold as a function of the moisture content and plate pressure.

$$E = a_0 + a_1 \times MC_{mold} + a_2 \times MC_{mold}^2 + a_3 \times P_{mold} + a_4 \times P_{mold}^2$$

Where:

a_0,a_1,a_2,a_3,a_4 = regression coefficients

MC_{mold} = laboratory moisture content from proctor point (has a corresponding P_{mold})

8. The range of target moduli values can be obtained by entering the acceptable moisture content range and and field plate pressure into the regression analysis equation.

$$E_{target} = a_0 + a_1 \times MC_{field} + a_2 \times MC_{field}^2 + a_3 \times P_{field} + a_4 \times P_{field}^2$$

Where:

E_{target} = target modulus values

MC_{field} = the field moisture content

P_{field} = field plate pressure

$$P_{field} = \frac{F_{field}}{\pi \frac{D_{field}}{2}}$$

Where:

F_{field} = applied load from the LWD in the field

D_{field} = the diameter of the LWD plate in the field

9. The target modulus can be compared with the measured field modulus to asses compaction quality following AASHTO TP 456-01 Section 5.

10. Report

The test report shall include the following:

- Acceptable moisture content range in percentage
- Maximum laboratory dry density in pounds per cubic foot
- Assumed Poisson Ratio from the table provided in AASHTO TP 123-01
- Target modulus values for the desired field plate size (150, 200, or 300 mm)
- The LWD device type, drop weight, plate diameter, and drop heights
- Identifying information – project number, lab sample number, technician, date, etc
- Any additional notes including corrections to values such as excess water drainage, oversized particles, etc

Appendix C – CABC

Standard Specifications for Highway Construction Section 703 Aggregates – Base Course, Gradation D-1 Material Specification

CABC Laboratory Test Results

CABC LWD Test Results

SECTION 703
AGGREGATES

703-2.01 FINE AGGREGATE FOR CONCRETE. Meet AASHTO M 6, Class A, except as follows:

Delete paragraph 8.2 of AASHTO M 6.

Delete the following methods of sampling and testing:

AASHTO T 11	Amount of Material Finer than No. 200 Sieve
AASHTO T 27	Sieve Analysis
AASHTO T 103	Soundness (freezing and thawing)

And substitute the following:

ATM 304 (Method A)	Sieve Analysis of Fine and Coarse Aggregates and Material Finer Than No. 200 Sieve in Mineral Aggregates by Washing

Add the following: Meet AASHTO T 104 using sodium sulfate solution.

In AASHTO M 6, Section 7.1, table entitled "Deleterious Substances Limits", change the maximum percent of material by mass finer than No. 200 Sieve in a. (concrete subject to surface abrasion), from 2.0 to 3.0.

703-2.02 COARSE AGGREGATE FOR CONCRETE. AASHTO M 80, Class B, except as follows:

Delete the following methods of sampling and testing:

AASHTO T 11	Amount of Material Finer than No. 200 Sieve
AASHTO T 27	Sieve Analysis

And substitute the following:

ATM 304 (Method A)	Sieve Analysis of Fine and Coarse Aggregates and Material Finer Than No. 200 Sieve in Mineral Aggregates by Washing

Add the following: Meet AASHTO T 104 using sodium sulfate solution.

703-2.03 AGGREGATE FOR BASE AND SURFACE COURSE. Crushed stone or crushed gravel, consisting of sound, tough, durable pebbles or rock fragments of uniform quality. Free from clay balls, vegetable matter, or other deleterious matters. Meet Table 703-1:

TABLE 703-1
AGGREGATE QUALITY PROPERTIES FOR BASE AND SURFACE COURSE

PROPERTY	BASE COURSE	SURFACE COURSE	TEST METHOD
L.A. Wear,%	50, max.	45, max.	AASHTO T 96
Degradation Value	45, min.	45, min.	ATM 313
Fracture,%	70, min.	70, min., 1 Face	ATM 305
Liquid Limit	---	35, max.	ATM 204
Plastic Index	6, max.	10, max.	ATM 205
Sodium Sulfate Loss,%	9, max. (5 cycles)	9, max. (5 cycles)	AASHTO T 104

Meet Table 703-2 aggregate gradation requirements, as determined by ATM 304:

TABLE 703-2
AGGREGATE GRADATION FOR BASE AND SURFACE COURSE
Percent Passing by Weight

SIEVE	GRADATION			
	BASE COURSE		SURFACE COURSE	
	C-1	D-1	E-1	F-1
1-1/2 in.	100			
1 in.	70-100	100	100	100
3/4 in.	60-90	70-100	70-100	85-100
3/8 in.	45-75	50-80	50-85	60-100
No. 4	30-60	35-65	35-65	50-85
No. 8	22-52	20-50	20-50	40-70
No. 50	6-30	6-30	15-30	25-45
No. 200	0-6	0-6	8-15	8-20

703-2.04 AGGREGATE FOR HOT MIX ASPHALT. Process and crush aggregate that is free from clay balls, organic matter, other deleterious material, and not coated with dirt or other finely divided mineral matter. Aggregate used must consist of sound, tough, durable rock of uniform quality.

Remove all natural fines passing a No. 4 sieve before crushing aggregates for Type IV mixes.

Coarse Aggregate**.** Aggregate retained on the No. 4 Sieve.

Meet Table 703-3 requirements:

TABLE 703-3
COARSE AGGREGATE QUALITY FOR HMA

Description	**Specification**	**Type II, Class A**	**Type I, Type II Class B, Type III**	**Type IV**	**Type V**	**Type SP**
LA Wear, % max.	AASHTO T 96	45	45	45	45	45
Degradation Value, min.	ATM 313	30	30	30	30	30
Sodium Sulfate Loss % max. (5 cycles)	AASHTO T 104	9	9	9	9	9
Fracture, % min.	ATM 305	90, 2 face	80, 1 face	90, 2 face	98, 2 face	90, 2 face
Flat-Elongated Pieces, % max. 1:5	ATM 306	8	8	8	8	8
Absorption, % max.	ATM 308	2.0	2.0	2.0	2.0	2.0
Nordic Abrasion, % max.	ATM 312	-	-	-	8.0	8.0

Fine Aggregate. Aggregate passing the No. 4 sieve. Fine aggregate shall meet the quality requirements of AASHTO M 29, including S1.1, Sulfate Soundness.

State of Alaska Dept. of Transportation Northern Region Materials Lab

SOIL and AGGREGATE REPORT

Lab Number: **AWW-BC-SD-1**

Project:	Airport Way West Bicycle and Ped		
Program:	NFHWY00447	***Date Tested:***	6/17/22
Ledger:		***Field Number:***	AWW-BC-SD-1
Submitted by:	S. Doetsch	***Date Rec:***	9-Jun-22
Date Sampled:	9-Jun-22	***Material Site:***	Exclusive Southside Pit
Sample Type:	Stockpile	***Site Location:***	
Station:		***Item #:***	
Offset:		***Sample of:***	Base Course, D1
Depth:			

TEST METHOD	DESCRIPTION	NRML	FIELD	SPECS
WAQTC FOP for T-89	Liquid Limit			
WAQTC FOP for T-90	Plastic Index			
Coarse Agg Specific Gravity	Bulk	2.724		
WAQTC FOP for T-85	SSD	2.736		
	Apparent	2.758		
	Absorption	0.5%		
Fine Agg Specific Gravity	Bulk			
AASHTO T-84 / T-100	SSD			
ASTM C128 / D854	Apparent	2.758		
	Absorption			
Sodium Sulfate Soundness	Coarse			
ASTM C88 AASHTO T-104	Fine			
ASTM C131 AASHTO T-96	LA Abrasion			
ATM 313	Degradation			
AASHTO T-112	Friable Particles			
ATM 203	Organic by Ignition			
ASTM C40 AASHTO T-21	Organic PPM			
WAQTC FOP for T-255 / 265	Moisture Content			
ATM 306	Flat & Elongated			
WAQTC FOP for T-176	Sand Equivalent			
	pH of Soil			
Fracture	Single Face			
WAQTC FOP for TP-61	Double Face			
	Fineness Modulus			
	% Deleterious			

WAQTC FOP for T-27/T-11

mm	inches	NRML	FIELD	SPECS
100	4"			
75	3"			
50.0	2"			
37.5	1 1/2"			
25.0	1"	100		
19.0	3/4"	99		
12.5	1/2"	86		
9.50	3/8"	76		
4.75	#4	53		
2.36	#8	39		
2.00	#10	36		
1.180	#16	31		
0.600	#30	26		
0.425	#40	23		
0.300	#50	16		
0.250	#60	16		
0.180	#80	7		
0.150	#100	6		
0.075	#200	3.2		
-3" #200				
Hydro. AASHTO T-88	.020mm			
	.005mm			
	.002mm			
	.001mm			

Acceptance/Assurance Comparison

Acceptable | Unacceptable | QA Engineer/Designee

Date:

Remarks:3 increments, Gilson R, Sieve stack 3. MaryAnn 2. Vibe Table Standard Density.

18June22

Matt Culley *Date:*

NRML Supervisor

QA Review *Signature:*

Comments: *Date:*

OVERSIZE CORRECTION WORKSHEET

State of Alaska DOT&PF Northern Region

ENGLISH

Project Name: Airport Way West Bicycle and Ped
Std. Density Lab #: AWW-BC-SD-1

Max. Dry Density: 141.0 (Lb/ft^3)
Bulk SpG: 2.724

% Pass 3/4"	Corrected Density	% Pass 3/4"	Corrected Density
95	142.2	77	146.8
94	142.5	76	147.0
93	142.7	75	147.3
92	143.0	74	147.5
91	143.2	73	147.8
90	143.4	72	148.1
89	143.7	71	148.3
88	143.9	70	148.6
87	144.2	69	148.9
86	144.4	68	149.1
85	144.7	67	149.4
84	145.0	66	149.7
83	145.2	65	149.9
82	145.5	64	150.2
81	145.7	63	150.5
80	146.0	62	150.8
79	146.2	61	151.0
78	146.5	60	151.3

METRIC

Max. Dry Density: 2259 (Kg/m^3)
Bulk SpG: 2.724

% Pass 3/4"	Corrected Density	% Pass 3/4"	Corrected Density
95	2278.1	77	2351.0
94	2282.1	76	2355.2
93	2286.0	75	2359.4
92	2290.0	74	2363.6
91	2293.9	73	2367.8
90	2297.9	72	2372.0
89	2301.9	71	2376.3
88	2305.9	70	2380.6
87	2309.9	69	2384.9
86	2314.0	68	2389.2
85	2318.0	67	2393.5
84	2322.1	66	2397.8
83	2326.2	65	2402.2
82	2330.3	64	2406.5
81	2334.4	63	2410.9
80	2338.5	62	2415.3
79	2342.6	61	2419.7
78	2346.8	60	2424.2

*NOTE: Use 70% Corrected Density value for all values below 70%

HDL ENGINEERING Consultants LLC

AGGREGATE/SOILS TEST REPORT

PROJECT:	LWD QA	**DATE TAKEN:**	7/25/2022
PROJECT NO.:	22-112-2	**DATE TESTED:**	7/25/2022
CLIENT:	AK DOT/PF	**TESTED BY:**	NP
SAMPLE NO.:	22P1037	**REVIEWED BY:**	JAB
LOCATION:	NA	**DESCRIPTION:**	CABC

SIEVE ANALYSIS TEST

(ASTM D422)

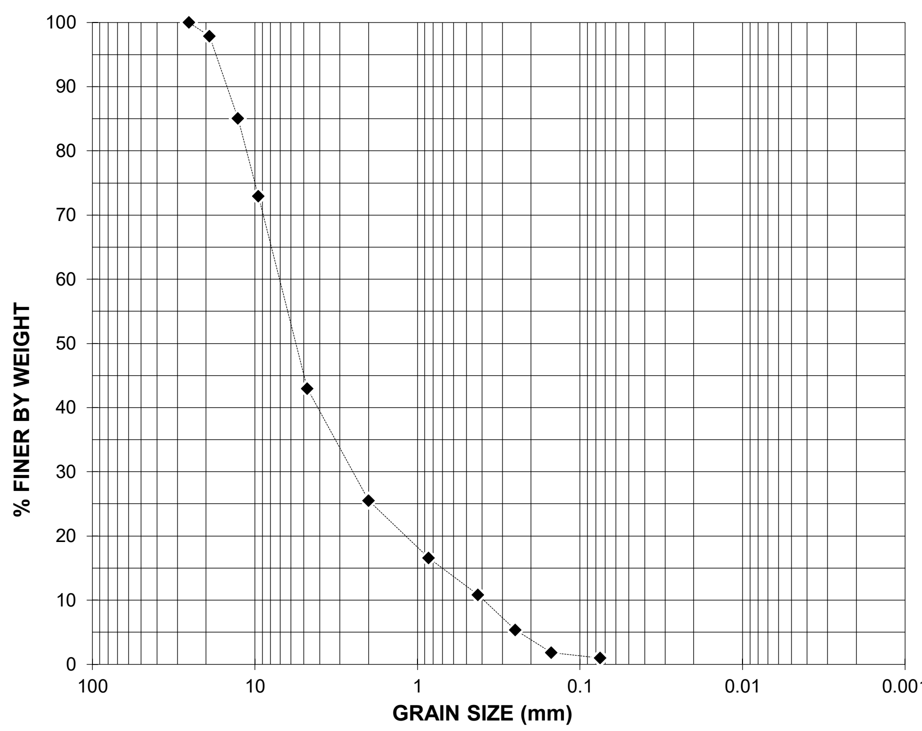
Sieve Size	Diameter (mm)	Total % Passing
6"	152.4	
4"	100.0	
3"	76.2	
2"	50.8	
1"	25.4	100
3/4"	19.0	98
1/2"	12.7	85
3/8"	9.5	73
#4	4.75	43
#10	2.00	25
#20	0.85	17
#40	0.425	11
#60	0.25	5
#100	0.15	2
#200	0.075	1.0

% Gravel:	57.0
%Sand:	42.0
% Fines:	1.0
D60:	7.45
D30:	2.71
D10:	0.40
Cu:	18.7
Cc:	2.5
% .02 mm:	
% Moisture:	0.2
Fine Modulus:	

(ASTM D4318)

Liquid Limit:	
Plastic Limit:	
Plastic Index:	

GRAIN SIZE DISTRIBUTION



HYDROMETER TEST

(ASTM D422)

Elapsed Time (min)	Diameter (mm)	Total % Passing
0		
0.5		
1		
2		
5		
8		
15		
30		
60		
250		
1440		

(ASTM C127)

Bulk SpG:	
SSD SpG:	
Apparent SpG:	
% Absorption:	

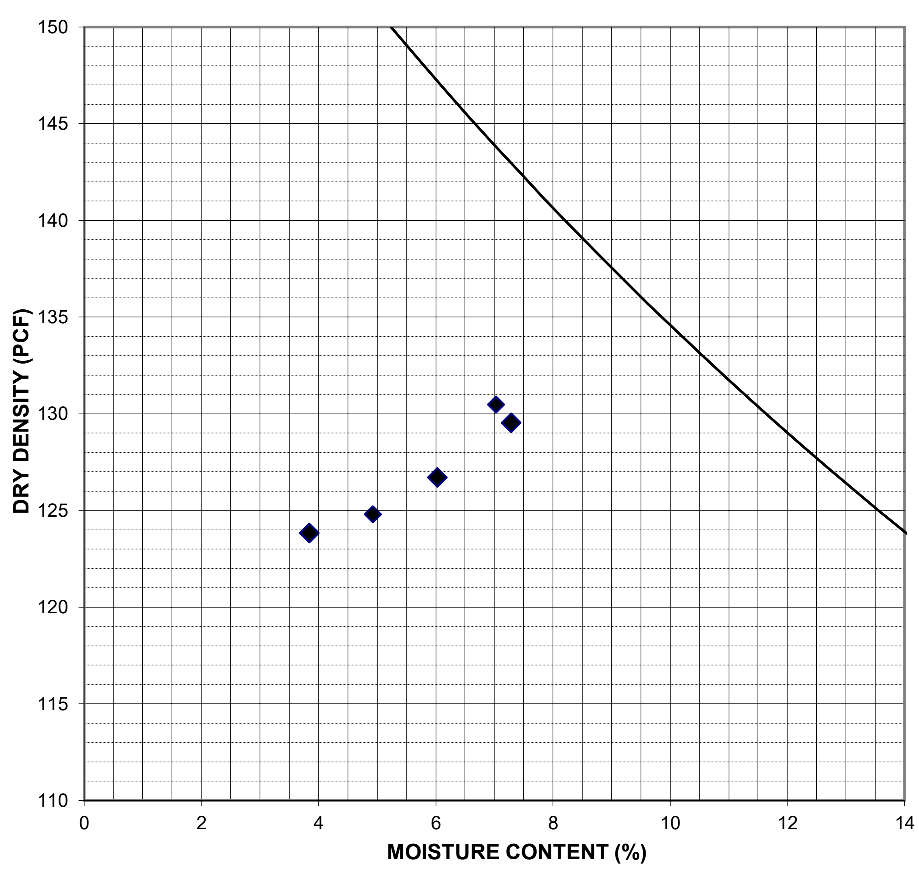
(ASTM C128)

Bulk SpG:	
SSD SpG:	
Apparent SpG:	
% Absorption:	

(ASTM D1557)

Dry Den (U):	130.5
Dry Den (C):	130.5
M% (U):	7.0%
M% (C):	7.0%
SpG (assumed):	2.75
M-D Test Method:	

MOISTURE-DENSITY RELATIONSHIP



CLASSIFICATION: Well Graded Gravel w/Sand

USC: GW

FROST CLASS:

Remarks: Gradation w/o extraction

Revised to include proctor

JOHN A. BUZDOR, P.E. 4/24/2023

3335 Arctic Blvd, Suite 100
Anchorage, AK 99503
Phone: (907) 564-2120

Airport Way CABC Data

The following sections present the results of the control strip, laboratory testing, and on-grade testing performed on the Airport Way CABC material.

Control Strip

Figure C1 shows the deflection and modulus values measured with the Zorn and Dynatest LWD's after each roller pass during the control strip test. The DOT&PF rover ended the test after seven (7) passes because the results indicated that compaction was damaging the material and further effort would decrease density. The results presented in Figure C1 also support that conclusion since the deflection increased and modulus decreased with continued compaction. In the box and whisker plots below, the "X" denotes the mean of the data set and the line inside the box denotes the median.

Figure C1. CABC Control Strip Roller Pass Results

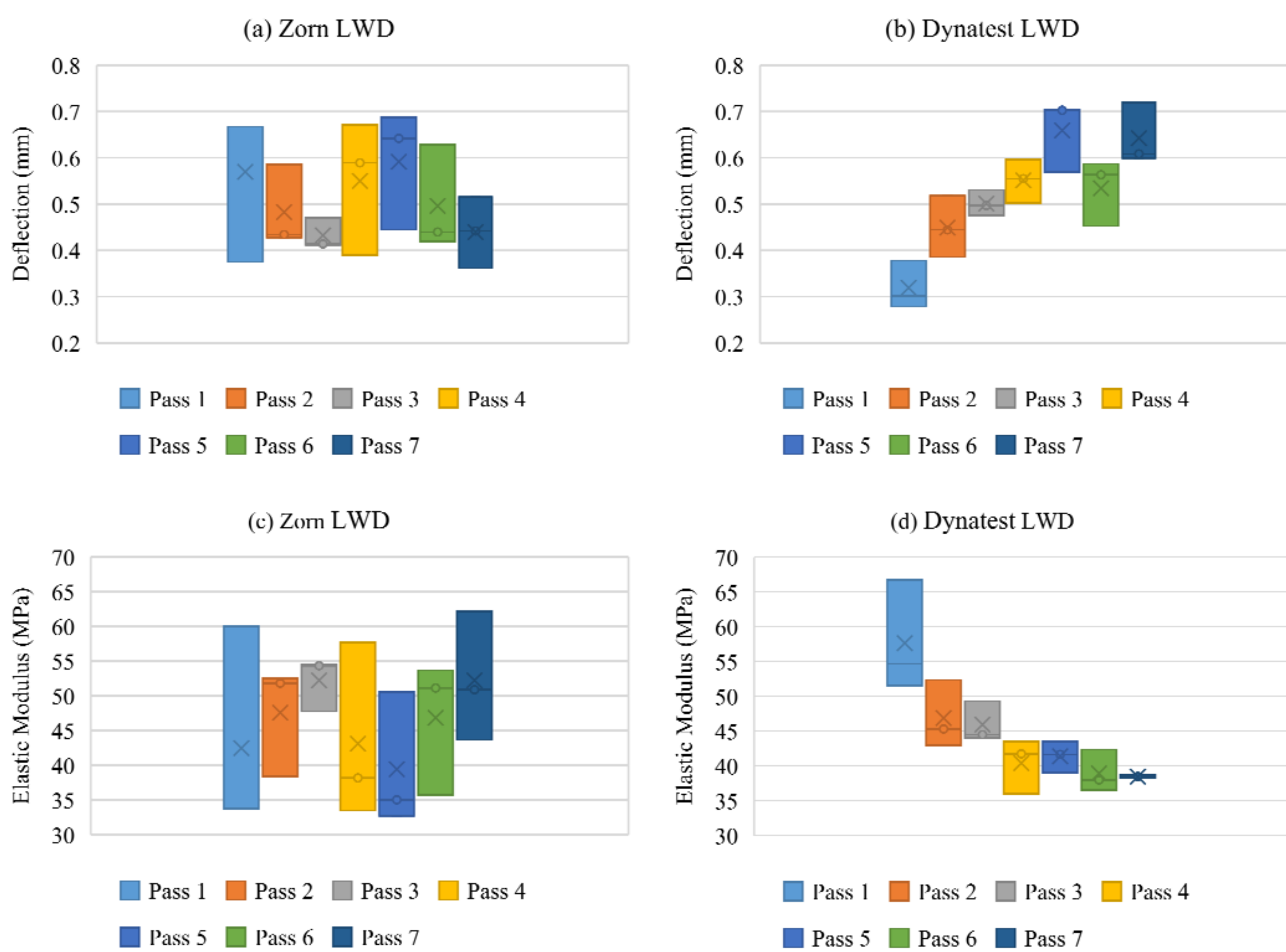


Figure C2 presents the deflection and elastic modulus values measured with the Zorn and Dynatest LWD devices compared with the measured dry density measured with a nuclear moisture-density gauge during the control strip test.

Figure C2. CABC Control Strip Results

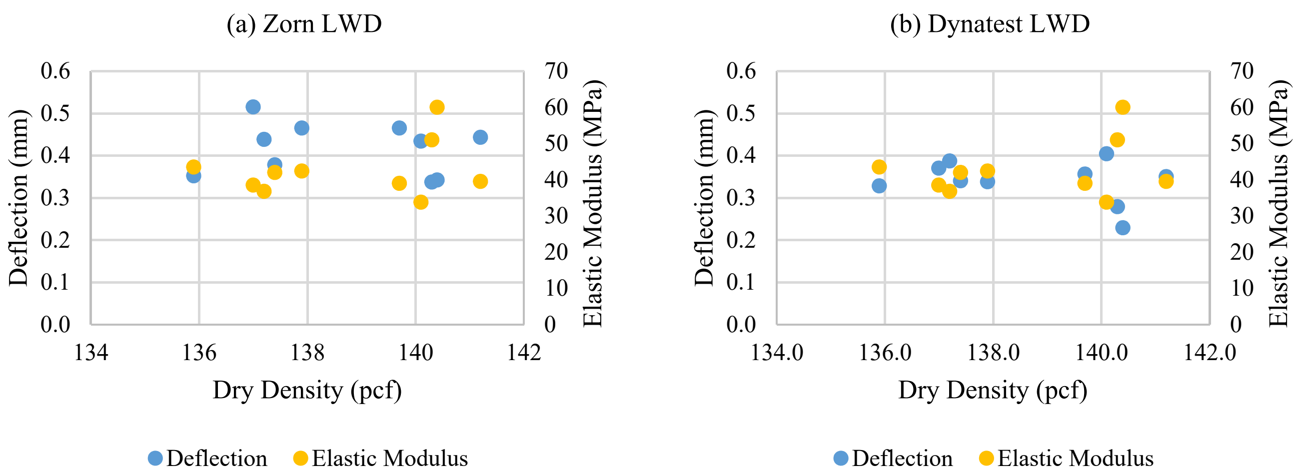


Figure C3 presents the CABC elastic modulus and deflection values measured on-grade compared to the measured dry density. The vertical red lines in the figures correspond to the density acceptance criteria (95% of the maximum dry density). Other states use 80% of the LWD-TV as the acceptance criteria for modulus values and 120% of the LWD-TV as the acceptance criteria for deflection values. For reference, the horizontal red lines in Figures C3a and C3b correspond to the calculated LWD acceptance values (80% of the LWD-TV) for elastic modulus using the control strip results and the horizontal red lines in Figures C3c and C3d correspond to the calculated LWD acceptance values (120% of the LWD-TV) for deflection using the control strip results.

Figure C3. CABC On-Grade Test Results with Control Strip LWD-TV

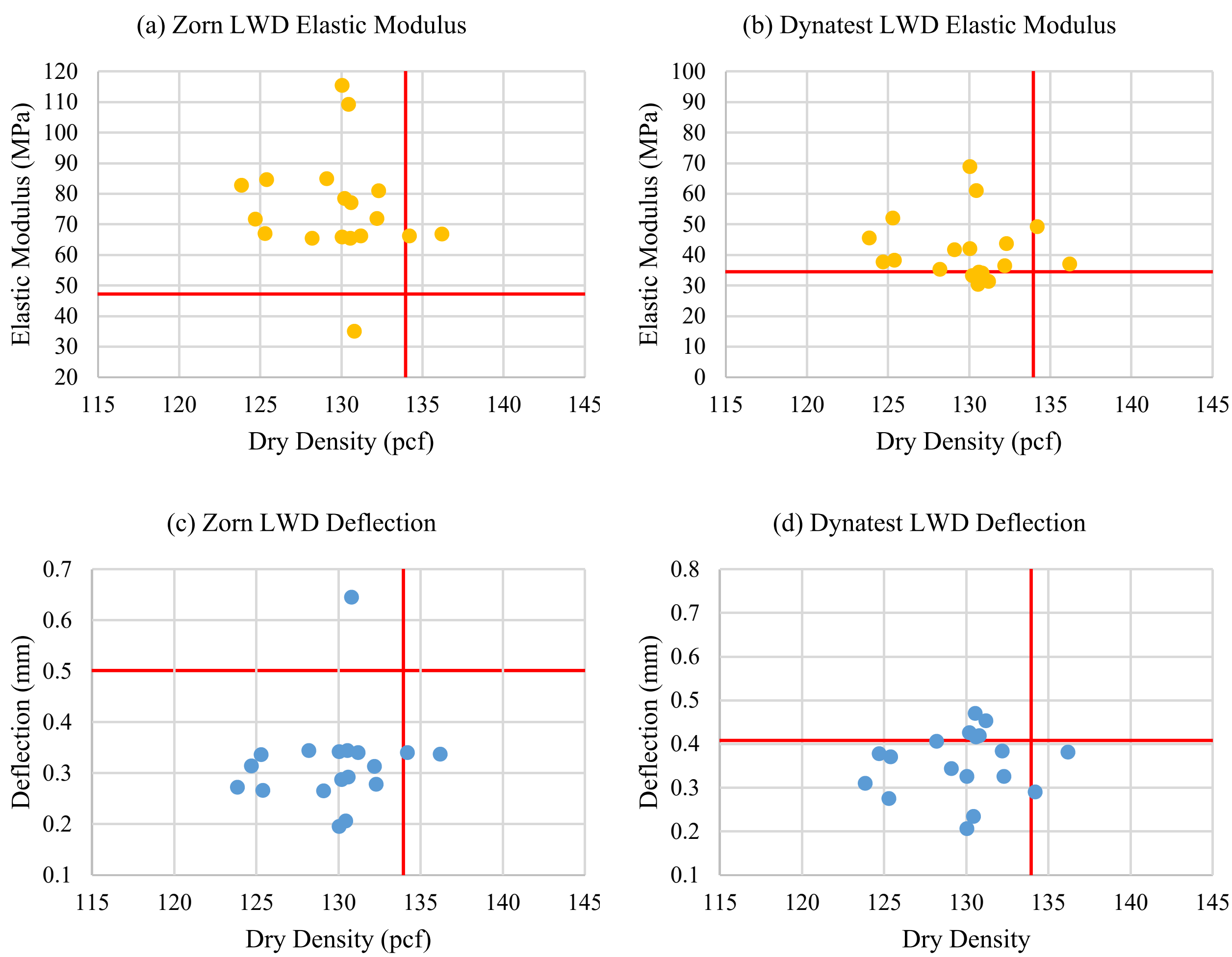
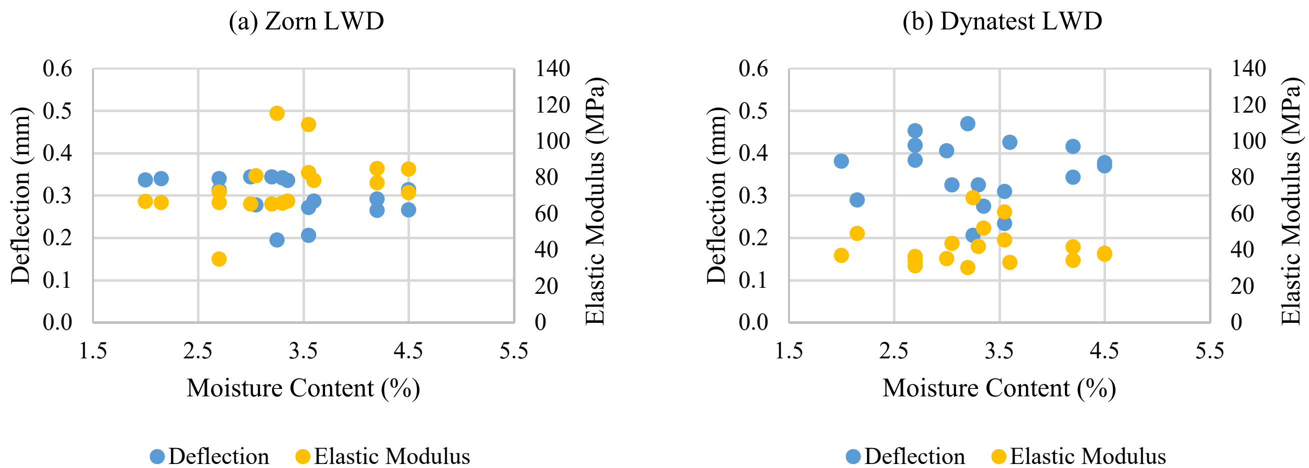


Figure C4 presents the on-grade deflection and elastic modulus values compared with the in-situ moisture content.

Figure C4. CABC On-Grade Testing and Moisture Content Results



Laboratory Testing

The research team conducted laboratory testing with the Dynatest LWD to establish laboratory LWD-TVs in accordance with the procedures previously discussed. Figure C5 presents the measured deflection and elastic modulus values compared with the laboratory measured dry densities and moisture contents.

Figure C5. CABC Laboratory Testing Results

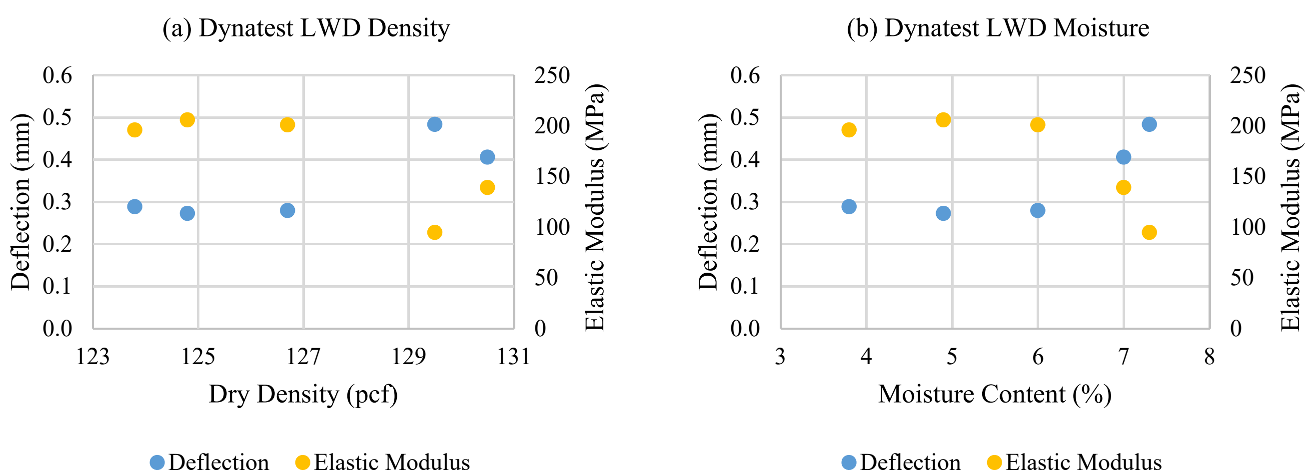


Figure C6 presents the on-grade elastic modulus values compared with the LWD-TVs calculated using the laboratory method. The red line represents the 1:1 line where data points above the red line meet the acceptance criteria and data points below the red line are fail to meet the acceptance criteria.

Figure C6. CABC On-Grade and Laboratory LWD-TVs

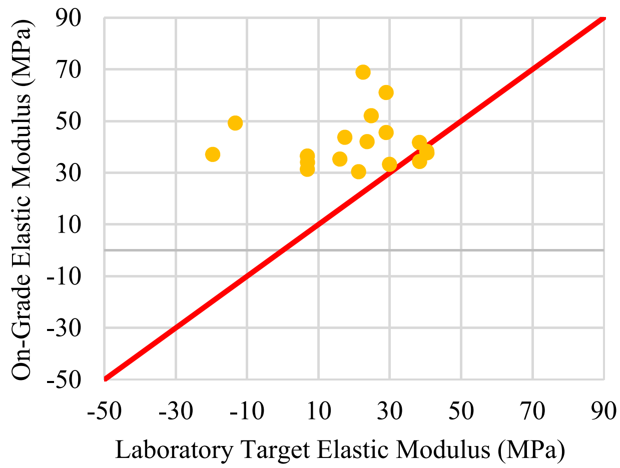


Table C1 presents the Control Strip test results for the CABC. Control Strip test results include average elastic modulus and average deflection measured by each LWD model. For each roller pass, dry density and moisture content were not recorded during the Control Strip testing. The CABC material was sourced from the Exclusive Paving southside pit in Fairbanks. The Control Strip testing utilized a CAT rubber tire vibratory drum roller for compaction.

Table C1. CABC Control Strip Testing Results

Test Number	Roller Pass Number	Zorn Average Elastic Modulus (MPa)	Dynatest Average Elastic Modulus (MPa)	Zorn Average Deflection (mm)	Dynatest Average Deflection (mm)
1	1	34	67	0.67	0.30
2	1	60	55	0.38	0.28
3	1	34	52	0.67	0.38
4	2	38	52	0.59	0.39
5	2	53	43	0.43	0.52
6	2	52	45	0.43	0.44
7	3	54	45	0.41	0.50
8	3	55	49	0.41	0.53
9	3	48	44	0.47	0.48
10	4	38	42	0.59	0.50
11	4	34	44	0.67	0.56
12	4	58	36	0.39	0.60
13	5	33	39	0.69	0.70
14	5	35	42	0.64	0.70
15	5	51	44	0.45	0.57
16	6	36	38	0.63	0.56
17	6	51	42	0.44	0.59
18	6	54	37	0.42	0.45
19	7	62	39	0.36	0.61
20	7	51	38	0.44	0.60
21	7	34	67	0.67	0.30

Table C2 presents the Control Strip testing results for the CABC. Control Strip results include dry density measured by a nuclear moisture-density gauge, average elastic modulus, and average deflection measured by each LWD model. Moisture content was not collected during this control strip. The CABC material was sourced from the Exclusive Paving southside pit in Fairbanks. The Control Strip testing utilized a CAT rubber tire vibratory drum roller for compaction.

Table C2. CABC Control Strip Testing Results

Test Number	Dry Density (pcf)	Moisture Content (%)	Zorn Average Elastic Modulus (MPa)	Dynatest Average Elastic Modulus (MPa)	Zorn Average Deflection (mm)	Dynatest Average Deflection (mm)
1	137.0	--	44	39	0.52	0.37
2	137.4	--	60	42	0.38	0.34
3	135.9	--	64	44	0.35	0.33
4	137.2	--	51	37	0.44	0.39
5	140.3	--	67	51	0.34	0.28
6	139.7	--	48	39	0.47	0.36
7	137.9	--	48	42	0.47	0.34
8	141.2	--	51	40	0.44	0.35
9	140.4	--	66	60	0.34	0.23
10	140.1	--	52	34	0.43	0.40

Table C3 presents the on-grade testing results for the CABC. On-grade results include dry density and moisture content measured by a nuclear moisture-density gauge, average elastic modulus, and average deflection measured by each LWD model. The CABC material was sourced from the Exclusive Paving southside pit in Fairbanks.

Table C3. CABC On-Grade Testing Results

Test Number	Dry Density (pcf)	Moisture Content (%)	Zorn Average Elastic Modulus (MPa)	Dynatest Average Elastic Modulus (MPa)	Zorn Average Deflection (mm)	Dynatest Average Deflection (mm)
1	134.2	2.2	66	49	0.34	0.29
2	136.2	2.0	67	37	0.34	0.38
3	130.2	3.6	78	33	0.29	0.43
4	130.6	4.2	77	34	0.29	0.42
5	130.6	3.2	65	30	0.34	0.47
6	132.3	3.1	81	44	0.28	0.33
7	132.2	2.7	72	36	0.31	0.38
8	130.8	2.7	35	34	0.65	0.42
9	131.2	2.7	66	31	0.34	0.45
10	123.9	3.6	83	46	0.27	0.31
11	124.7	4.5	72	38	0.31	0.38
12	130.5	3.6	109	61	0.21	0.23
13	129.1	4.2	85	42	0.27	0.34
14	125.4	4.5	85	38	0.27	0.37
15	130.1	3.3	115	69	0.20	0.21
16	130.1	3.3	66	42	0.34	0.33
17	128.2	3.0	65	35	0.34	0.41
18	125.3	3.4	67	52	0.34	0.28

Table C4 presents the laboratory testing results for the CABC. Laboratory results include moisture content measured in the laboratory, average elastic modulus, and average deflection measured by each LWD model. The CABC material was sourced from the Exclusive Paving southside pit in Fairbanks.

Table C4. CABC Laboratory Testing Results

Test Number	Dry Density (pcf)	Moisture Content (%)	Dynatest Average Deflection (mm)	Dynatest Average Elastic Modulus (MPa)	Measured Force (kN)	Applied Pressure (kPa)
1	123.8	3.8	0.29	196	7.6	417
2	124.8	4.9	0.27	206	7.5	413
3	126.7	6.0	0.28	201	7.5	413
4	129.5	7.3	0.48	95	6.8	373
5	130.5	7.0	0.41	139	7.6	417

Table C5 presents the LWD-TV values determined using the laboratory method and the on-grade elastic modulus values.

Table C5. CABC Laboratory LWD-TV and On-Grade Elastic Modulus Values

Test Number	Laboratory LWD-TV (MPa)	On-Grade Elastic Modulus (MPa)
1	-13	49
2	-20	37
3	30	33
4	38	34
5	21	30
6	17	44
7	7	36
8	7	34
9	7	31
10	29	46
11	40	38
12	29	61
13	38	42
14	40	38
15	23	69
16	24	42
17	16	35
18	25	52

Table C6 presents the regression outputs for the laboratory method.

Table C6. CABC Regression Outputs

	Coefficients	**Standard Error**	**T Stat**	**P-Value**	**Lower 95.0%**	**Upper 95.0%**
a_0	-142	40.6	-3.49	0.00329	-228	-55.092
a_1	74.4	14.1	5.27	0.0000951	44.3	104.473
a_2	-7.74	1.26	-6.15	0.0000187	-10.4	-5.058
a_3	0.261	0.111	2.34	0.0332	0.0237	0.498
a_4	-0.000192	0.000199	-0.965	0.350	-0.000617	0.000

Table C7 presents the regression statistics for the laboratory method.

Table C7. CABC Regression Statistics

Regression Statistics	
Multiple R	0.971
R Square	0.943
Adjusted R Square	0.927
Standard Error	6.97
Observations	20

Appendix D – Borrow A

Standard Specifications for Highway Construction – Selected Material, Type A Material Specification

Borrow A Laboratory Test Results

Borrow A LWD Test Results

TABLE 703-6
AGGREGATE GRADATION FOR COVER COAT MATERIAL
Percent Passing By Weight

	TYPE 2 COVER	TYPE 3 COVER AGGREGATE		
SIEVE	**AGGREGATE**	Grading A	Grading B	Grading C
1/2 in.	--	--	--	100
3/8 in.	100	100	100	90-100
No. 4	85-100	85-100	60-100	10-30
No. 8	--	0-25	0-10	0-8
No. 50	0-20	--	--	--
No. 200	0-1	0-1	0-1	0-1

Surface Treatment Material. Meet the gradation requirements of Table 703-7, as determined by ATM 304.

TABLE 703-7
AGGREGATE GRADATION FOR ASPHALT SURFACE TREATMENT

	GRADING Percent Passing by Weight						
SIEVE	A	B	C	D	E	F	G
1-1/2 in.	100	--	--	--	--	--	--
1 in.	90-100	100	--	--	--	--	--
3/4 in.	--	90-100	100	--	--	--	--
1/2 in.	0-15	20-55	90-100	100	100	--	--
3/8 in.	--	0-15	40-75	90-100	90-100	100	100
No. 4	--	--	0-15	0-10	10-30	75-100	85-100
No. 8	--	--	0-5	0-5	0-8	0-10	60-100
No. 200	0-1	0-1	0-1	0-1	0-1	0-1	0-10

703-2.06 MINERAL FILLER. Meet AASHTO M 17. Determine material grading using AASHTO T 37.

703-2.07 SELECTED MATERIAL. Meet the following requirements for the type specified. Obtain the Engineer's approval for the intended purpose, prior to use on the project.

1. Type A. Aggregate containing no muck, frozen material, roots, sod or other deleterious matter and with a plasticity index not greater than 6 as tested by ATM 204 and ATM 205. Meet the following gradation as tested by ATM 304:

Sieve	Percent Passing by Weight
No. 4	20-60%
No. 200	0-6%, determined on the minus 3-inch portion of the sample

2. Type B. Aggregate containing no muck, frozen material, roots, sod or other deleterious matter and with a plasticity index not greater than 6 as tested by ATM 204 and ATM 205. Meet the following gradation as tested by ATM 304:

Sieve	Percent Passing by Weight
No. 200	0-10% determined on the minus 3-inch portion of the sample

3. Type C. Earth, sand, gravel, rock, or combinations thereof containing no muck, peat, frozen material, roots, sod, or other deleterious matter and is compactable under the provisions of Subsections 203-3.04 or 203-3.05.

State of Alaska Dept. of Transportation Northern Region Materials Lab

SOIL and AGGREGATE REPORT

Lab Number: AWW-BM(A)/SB(F)-SD-1

Project:	Airport Way West Bicycle and Ped		
Program:	NFHWY00447	**Date Tested:**	6/16/22
Ledger:		**Field Number:**	AWW-BM(A)/SB(F)-SD-1
Submitted by:	A.Rose de la Cruz	**Date Rec:**	9-Jun-22
Date Sampled:	9-Jun-22	**Material Site:**	Exclusive Southside Pit
Sample Type:	Stockpile	**Site Location:**	
Station:		**Item #:**	
Offset:		**Sample of:**	Borrow A & Subbase F
Depth:			

TEST METHOD	DESCRIPTION	NRML	FIELD	SPECS
WAQTC FOP for T-89	Liquid Limit			
WAQTC FOP for T-90	Plastic Index			
Coarse Agg Specific Gravity	Bulk	2.682		
WAQTC FOP for T-85	SSD	2.692		
	Apparent	2.711		
	Absorption	0.4%		
Fine Agg Specific Gravity	Bulk			
AASHTO T-84 / T-100	SSD			
ASTM C128 / D854	Apparent	2.711		
	Absorption			
Sodium Sulfate Soundness	Coarse			
ASTM C88 AASHTO T-104	Fine			
ASTM C131 AASHTO T-96	LA Abrasion			
ATM 313	Degradation			
ATM 203	Organic by Ignition			
WAQTC FOP for T-255 / 265	Moisture Content			
ATM 306	Flat & Elongated			
WAQTC FOP for T-176	Sand Equivalent			
	pH of Soil			
Fracture	Single Face			
WAQTC FOP for TP-61	Double Face			
	% Deleterious			

WAQTC FOP for T-27/T-11				
mm	inches	NRML	FIELD	SPECS
100	4"			
75	3"			
50.0	2"	100		
37.5	1 1/2"	99		
25.0	1"	93		
19.0	3/4"	84		
12.5	1/2"	67		
9.50	3/8"	55		
4.75	#4	35		
2.36	#8	28		
2.00	#10	28		
1.180	#16	26		
0.600	#30	24		
0.425	#40	21		
0.300	#50	12		
0.250	#60	12		
0.180	#80	2		
0.150	#100	1		
0.075	#200	0.2		
-3" #200				
Hydro. AASHTO T-88	.020mm			
	.005mm			
	.002mm			
	.001mm			

Acceptance/Assurance Comparison

Acceptable | Unacceptable | QA Engineer/Designee

Date:

QA Review *Signature:*

Comments: *Date:*

Remarks:5 increments, Gilson R, Sieve stack 1. MaryAnn 1. Vibe Table Standard Density.

17June22

Matt Culley *Date:*

NRML Supervisor

OVERSIZE CORRECTION WORKSHEET

State of Alaska DOT&PF Northern Region

ENGLISH

Project Name: Airport Way West Bicycle and Ped
Std. Density Lab #: AWW-BM(A)/SB(F)-SD-1

Max. Dry Density: 136.4 (Lb/ft^3)
Bulk SpG: 2.682

% Pass 3/4"	Corrected Density	% Pass 3/4"	Corrected Density
95	137.7	77	142.5
94	137.9	76	142.7
93	138.2	75	143.0
92	138.5	74	143.3
91	138.7	73	143.6
90	139.0	72	143.9
89	139.2	71	144.1
88	139.5	70	144.4
87	139.8	69	144.7
86	140.0	68	145.0
85	140.3	67	145.3
84	140.6	66	145.6
83	140.8	65	145.8
82	141.1	64	146.1
81	141.4	63	146.4
80	141.6	62	146.7
79	141.9	61	147.0
78	142.2	60	147.3

METRIC

Max. Dry Density: 2185 (Kg/m^3)
Bulk SpG: 2.682

% Pass 3/4"	Corrected Density	% Pass 3/4"	Corrected Density
95	2205.4	77	2282.2
94	2209.6	76	2286.6
93	2213.7	75	2291.1
92	2217.9	74	2295.5
91	2222.0	73	2300.0
90	2226.2	72	2304.5
89	2230.4	71	2309.0
88	2234.7	70	2313.6
87	2238.9	69	2318.1
86	2243.2	68	2322.7
85	2247.4	67	2327.2
84	2251.7	66	2331.8
83	2256.0	65	2336.5
82	2260.4	64	2341.1
81	2264.7	63	2345.8
80	2269.1	62	2350.4
79	2273.4	61	2355.1
78	2277.8	60	2359.8

*NOTE: Use 70% Corrected Density value for all values below 70%

AGGREGATE/SOILS TEST REPORT

PROJECT:	LWD QA	**DATE TAKEN:**	7/25/2022
PROJECT NO.:	22-112-2	**DATE TESTED:**	7/25/2022
CLIENT:	AK DOT/PF	**TESTED BY:**	NP
SAMPLE NO.:	22P1036	**REVIEWED BY:**	JAB
LOCATION:	NA	**DESCRIPTION:**	BORROW A

SIEVE ANALYSIS TEST
(ASTM D422)

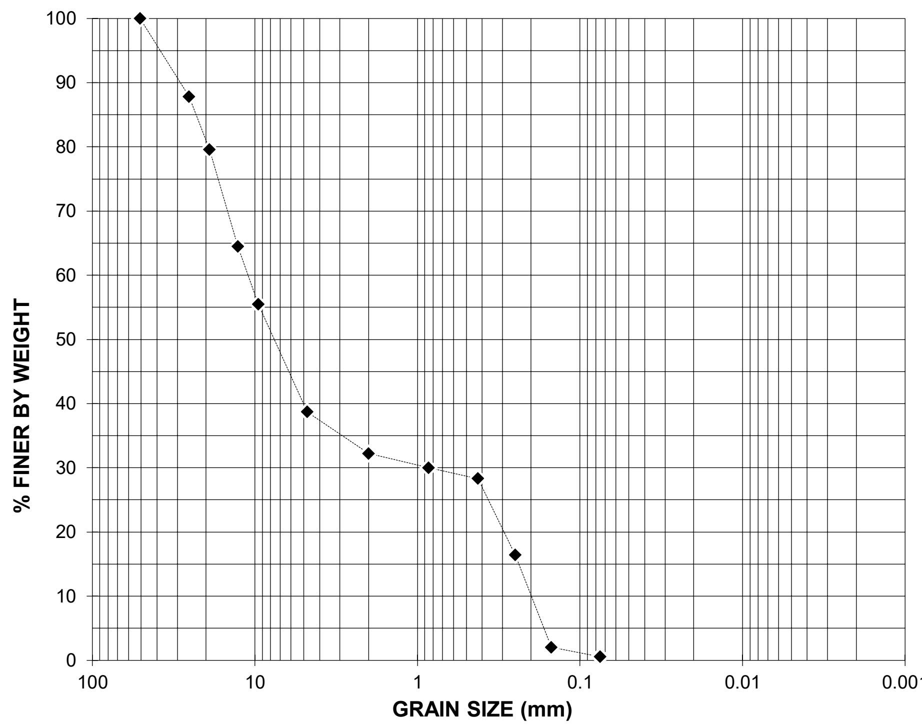
Sieve Size	Diameter (mm)	Total % Passing
6"	152.4	
4"	100.0	
3"	76.2	
2"	50.8	100
1"	25.4	88
3/4"	19.0	80
1/2"	12.7	64
3/8"	9.5	55
#4	4.75	39
#10	2.00	32
#20	0.85	30
#40	0.425	28
#60	0.25	16
#100	0.15	2
#200	0.075	0.6

% Gravel:	61.3
%Sand:	38.2
% Fines:	0.6
D60:	11.11
D30:	0.85
D10:	0.21
Cu:	54.1
Cc:	0.3
% .02 mm:	
% Moisture:	2.8
Fine Modulus:	

(ASTM D4318)

Liquid Limit:	
Plastic Limit:	
Plastic Index:	

GRAIN SIZE DISTRIBUTION



HYDROMETER TEST
(ASTM D422)

Elapsed Time (min)	Diameter (mm)	Total % Passing
0		
0.5		
1		
2		
5		
8		
15		
30		
60		
250		
1440		

(ASTM C127)

Bulk SpG:	
SSD SpG:	
Apparent SpG:	
% Absorption:	

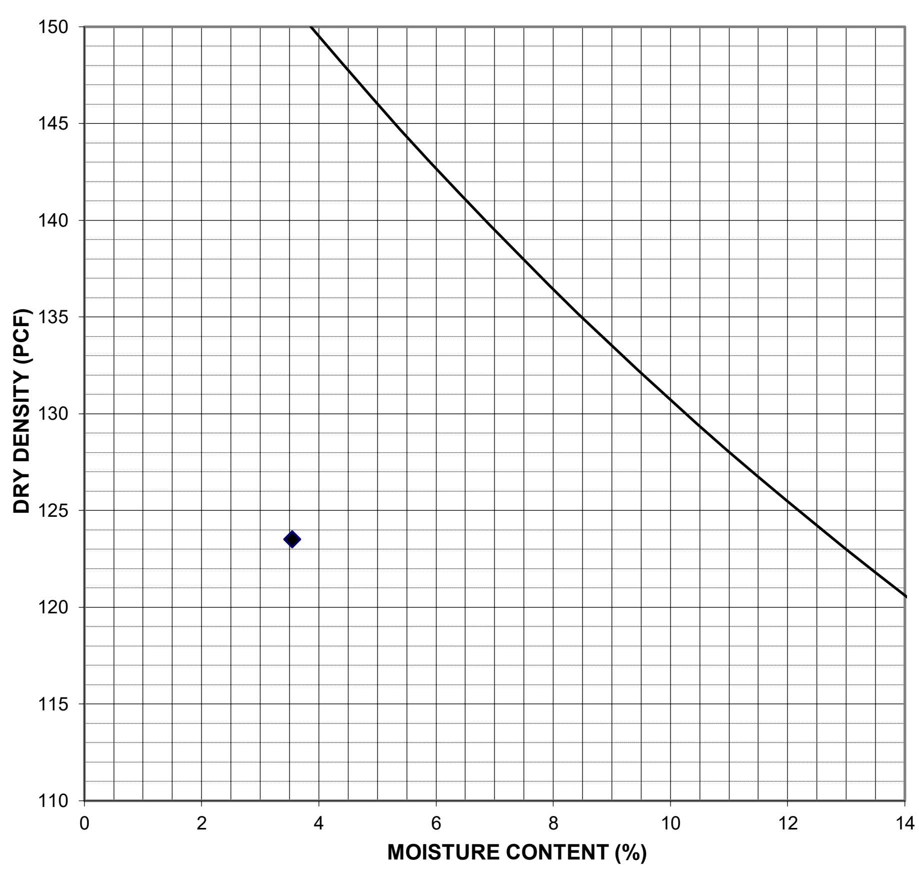
(ASTM C128)

Bulk SpG:	
SSD SpG:	
Apparent SpG:	
% Absorption:	

(ASTM D1557)

Dry Den (U):	140.0
Dry Den (C):	144.4
M% (U):	7.0%
M% (C):	5.8%
SpG (assumed):	2.65
M-D Test Method:	

MOISTURE-DENSITY RELATIONSHIP



CLASSIFICATION: Poorly Graded Gravel w/Sand
USC: GP
FROST CLASS:

Remarks: D4253 OF 22P1307

JOHN A. BUZDOR, P.E. 4/24/2023

3335 Arctic Blvd, Suite 100
Anchorage, AK 99503
Phone: (907) 564-2120

Subject to review by our Materials Engineer

REV 1-29-20

Airport Way Borrow A Data

The following sections present the laboratory testing and on-grade testing performed on the Airport Way Borrow A material.

Laboratory Testing Data

Figure D1 presents the measured deflection and elastic modulus values compared with the laboratory measured dry densities and moisture contents.

Figure D1. Borrow A Laboratory Testing Results

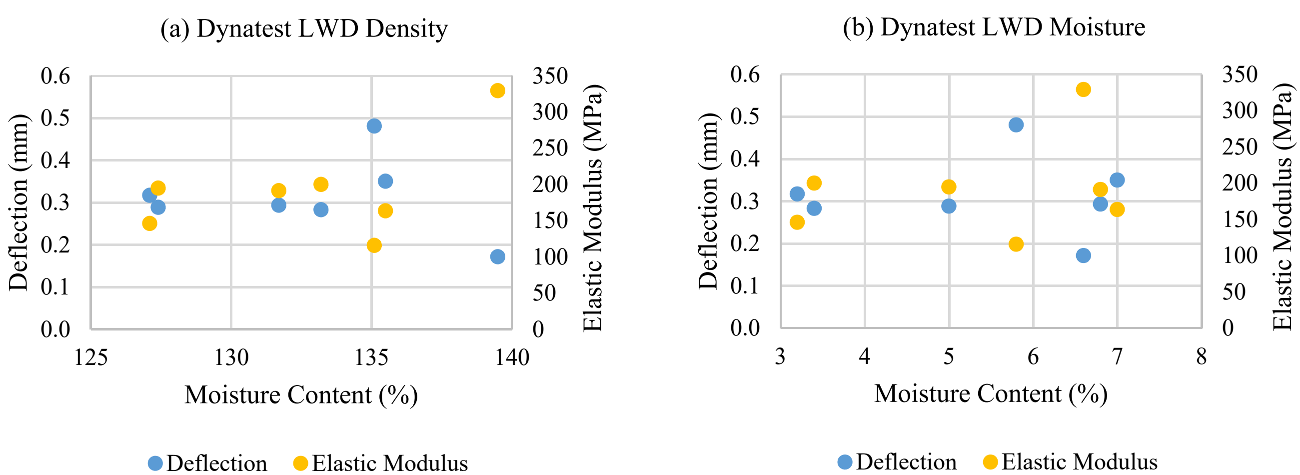


Figure D2 presents the on-grade elastic modulus values compared with the LWD-TVs calculated using the laboratory method.

Figure D2. Borrow A On-Grade and Laboratory Target Elastic Modulus Values

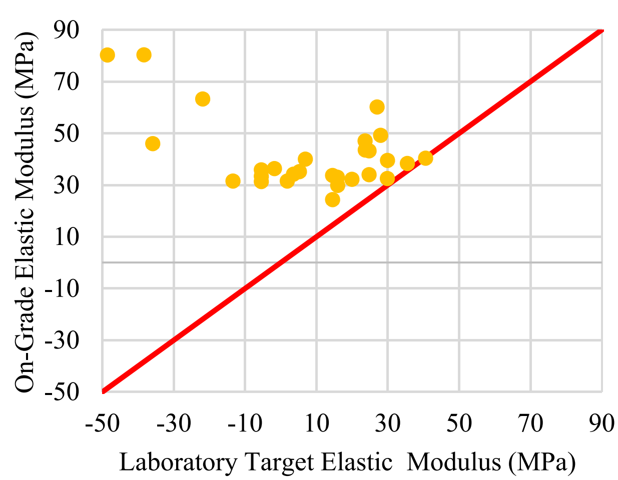


Figure D3 presents the on-grade deflection and elastic modulus values compared to the measured dry density.

Figure D3. Borrow A On-Grade Testing and Dry Density Results

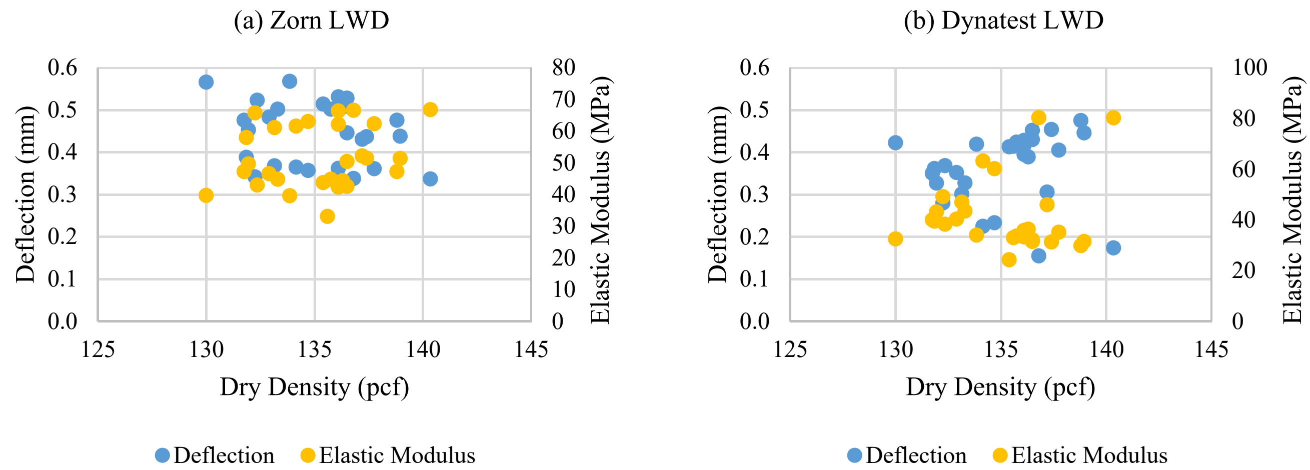


Figure D4 presents the on-grade deflection and elastic modulus values compared with the in-situ moisture content.

Figure D4. Borrow A On-Grade Testing and Moisture Content Results

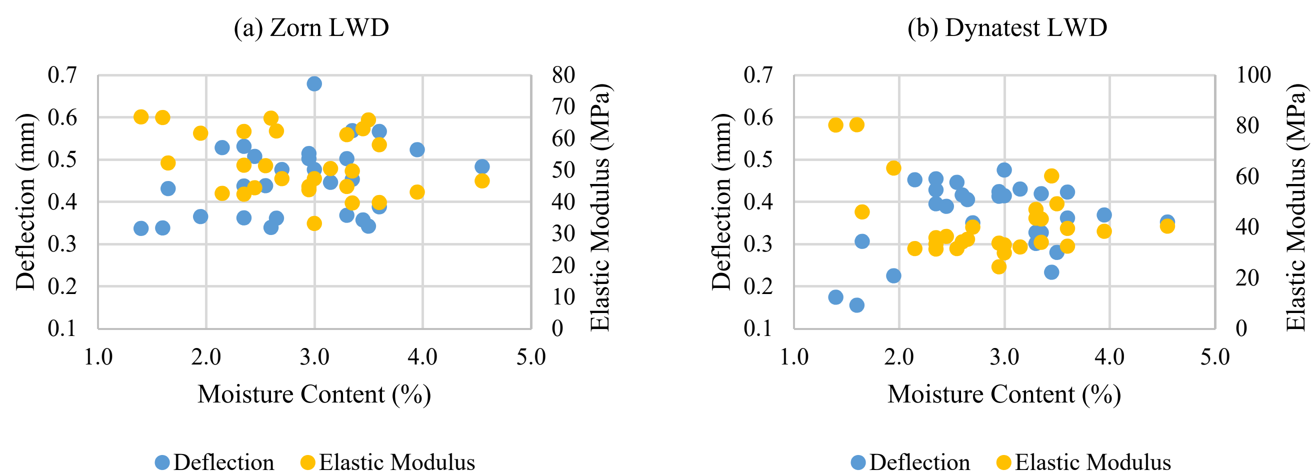


Table D1 presents the on-grade testing results for the Borrow A. On-grade results include dry density and moisture content measured by a nuclear moisture-density gauge, average elastic modulus, and average deflection measured by each LWD model. The Borrow A material was sourced from the Exclusive Paving southside pit in Fairbanks.

Table D1. Borrow A On-Grade Testing Results

Test Number	Dry Density (pcf)	Moisture Content (%)	Zorn Average Elastic Modulus (MPa)	Dynatest Average Elastic Modulus (MPa)	Zorn Average Deflection (mm)	Dynatest Average Deflection (mm)
1	134.2	2.0	62	63	0.37	0.23
2	137.2	1.7	52	46	0.43	0.31
3	136.8	1.6	67	80	0.34	0.16
4	140.4	1.4	67	80	0.34	0.17
5	137.8	2.7	62	35	0.36	0.41
6	136.5	3.2	50	32	0.45	0.43
7	135.4	3.0	44	24	0.51	0.41
8	138.8	3.0	47	30	0.48	0.48
9	136.1	2.6	66	34	0.34	0.42
10	136.1	2.4	42	33	0.53	0.43
11	136.1	2.4	62	36	0.36	0.40
12	137.4	2.4	51	31	0.44	0.45
13	139.0	2.6	51	32	0.44	0.45
14	135.6	3	33	33	0.68	0.41
15	136.5	2.2	43	32	0.53	0.45
16	133.9	3.4	40	34	0.57	0.42
17	136.3	2.5	44	36	0.51	0.39
18	135.8	3.0	45	34	0.50	0.42
19	133.2	3.3	61	47	0.37	0.30
20	133.3	3.3	45	44	0.50	0.33
21	131.8	2.7	47	40	0.48	0.35
22	134.7	3.5	63	60	0.36	0.23
23	132.9	4.6	47	40	0.48	0.35
24	132.4	4.0	43	38	0.52	0.37
25	130.0	3.6	40	33	0.57	0.42
26	132.0	3.4	50	43	0.45	0.33
27	131.9	3.6	58	40	0.39	0.36
28	132.3	3.5	66	49	0.34	0.28

Table D2 presents the laboratory testing results for the Borrow A. Laboratory results include moisture content measured in the laboratory, average elastic modulus, and average deflection measured by each LWD model.

Table D2. Borrow A Laboratory Testing Results

Test Number	Dry Density (pcf)	Moisture Content (%)	Dynatest Average Deflection (mm)	Dynatest Average Modulus (MPa)	Measured Force (kN)	Applied Pressure (kPa)
1	127.1	3.2	0.32	146	7.5	411
2	127.4	5.0	0.29	195	7.6	417
3	131.7	6.8	0.29	191	7.6	418
4	133.2	3.4	0.28	200	7.6	417
5	135.5	7.0	0.35	164	7.6	415
6	139.5	6.6	0.17	329	7.5	413
7	135.1	5.8	0.48	116	7.4	404

Table D3 presents the LWD-TVs determined using the laboratory method and the on-grade elsatic modulus values.

Table D3. Borrow A Laboratory LWD-TV and On-Grade Elastic Modulus Values

Test Number	Laboratory LWD-TV (MPa)	On-Grade Modulus (MPa)
1	-22	63
2	-36	46
3	-38	80
4	-49	80
5	5	35
6	20	32
7	15	24
8	16	30
9	4	34
10	-5	33
11	-5	36
12	-5	31
13	2	32
14	16	33
15	-13	32
16	25	34
17	-2	36
18	15	34
19	24	47
20	24	44
21	7	40
22	27	60
23	41	40
24	36	38
25	30	33
26	25	43
27	30	40
28	28	49

Table D4 presents the regression outputs for the laboratory method.

Table D4. Borrow A Regression Outputs

	Coefficients	**Standard Error**	**T Stat**	**P-Value**	**Lower 95.0%**	**Upper 95.0%**
a_0	115	128	0.897	0.379	-151	380
a_1	-51.5	50.9	-1.01	0.323	-157	54.2
a_2	5.57	5.02	1.11	0.279	-4.83	16.0
a_3	0.502	0.471	1.07	0.298	-0.474	1.48
a_4	-0.000679	0.000824	-0.824	0.419	-0.00239	0.00103

Table D5 presents the regression statistics for the laboratory method.

Table D5. Borrow A Regression Statistics

Regression Statistics	
Multiple R	0.464
R Square	0.216
Adjusted R Square	0.0731
Standard Error	33.4
Observations	27

Appendix E – Subbase F

Airport Way West Improvements Project Special Provisions Section 703 Aggregates – Subbase, Grading F Material Specification

Subbase F Laboratory Test Results

Subbase F LWD Test Results

SECTION 702
ASPHALT MATERIALS

11/16/20 (N82)
702-2.01 ASPHALT BINDER. *Delete the first paragraph and substitute the following:* Meet AASHTO M 320 for PG 52-28 binder.

Meet AASHTO M 332 for PG 52E-40 binder, except that J_{NR} Diff (AASHTO T 350) and Direct Tension (AASHTO T 314) do not apply. PG 52E-40 binder shall have a minimum Percent $Recovery_{3.2}$ of 75% according to AASHTO T 350.

SECTION 703
AGGREGATES

12/08/15 (N63)
703-2.09 SUBBASE. *Add the following:*

Subbase, Grading F. Aggregate containing no muck, frozen material, roots, sod or other deleterious matter and with a plasticity index not greater than 6 as tested by ATM 204 and ATM 205. Table 703-8 and the first paragraph of Subsection 703-2.09 do not apply to Grading F. Meet the following gradation as tested by ATM 304:

Sieve	Percent Passing by Weight
2 in	100%
No. 4	15-65%
No. 200	0-6%

Add the following subsection:

703-2.17 SHOT ROCK FOUNDATION FILL. Meet the following requirements. Obtain Engineer's approval for intended purpose, prior to use on project.

Evenly graded stones that are hard, angular, and of uniform quality. Stones shall have a minimum of two fractured faces that meet the definition of fractured face detailed within test method ATM 305 of the State of Alaska Department of Transportation and Public Facilities Alaska Test Methods Manual. The material shall contain no muck, frozen material, roots, sod or other deleterious material. Breadth and thickness of stones shall be a minimum of ¼ of their length.

Meet the following gradation for the class specified:

TABLE 703-15
AGGREGATE GRADATION FOR SHOT ROCK FOUNDATION FILL

Particle Size (least dimension)		Portion
Class I	Class II	
Greater than 7 inches	Greater than 12 inches	0%
3 inches to 7 inches	5 inches to 12 inches	95% - 100%
Less than 3 inches	Less than 5 inches	0% - 5%

SOIL and AGGREGATE REPORT

Lab Number: **AWW-BM(A)/SB(F)-SD-1**

Project:	Airport Way West Bicycle and Ped		
Program:	NFHWY00447	***Date Tested:***	6/16/22
Ledger:		***Field Number:***	AWW-BM(A)/SB(F)-SD-1
Submitted by:	A.Rose de la Cruz	***Date Rec:***	9-Jun-22
Date Sampled:	9-Jun-22	***Material Site:***	Exclusive Southside Pit
Sample Type:	Stockpile	***Site Location:***	
Station:		***Item #:***	
Offset:		***Sample of:***	Borrow A & Subbase F
Depth:			

TEST METHOD	DESCRIPTION	NRML	FIELD	SPECS
WAQTC FOP for T-89	Liquid Limit			
WAQTC FOP for T-90	Plastic Index			
Coarse Agg Specific Gravity	Bulk	2.682		
WAQTC FOP for T-85	SSD	2.692		
	Apparent	2.711		
	Absorption	0.4%		
Fine Agg Specific Gravity	Bulk			
AASHTO T-84 / T-100	SSD			
ASTM C128 / D854	Apparent	2.711		
	Absorption			
Sodium Sulfate Soundness	Coarse			
ASTM C88 AASHTO T-104	Fine			
ASTM C131 AASHTO T-96	LA Abrasion			
ATM 313	Degradation			
ATM 203	Organic by Ignition			
WAQTC FOP for T-255 / 265	Moisture Content			
ATM 306	Flat & Elongated			
WAQTC FOP for T-176	Sand Equivalent			
	pH of Soil			
Fracture	Single Face			
WAQTC FOP for TP-61	Double Face			
	% Deleterious			

WAQTC FOP for T-27/T-11				
mm	**inches**	**NRML**	**FIELD**	**SPECS**
100	4"			
75	3"			
50.0	2"	100		
37.5	1 1/2"	99		
25.0	1"	93		
19.0	3/4"	84		
12.5	1/2"	67		
9.50	3/8"	55		
4.75	#4	35		
2.36	#8	28		
2.00	#10	28		
1.180	#16	26		
0.600	#30	24		
0.425	#40	21		
0.300	#50	12		
0.250	#60	12		
0.180	#80	2		
0.150	#100	1		
0.075	#200	0.2		
-3" #200				
Hydro. AASHTO T-88	.020mm			
	.005mm			
	.002mm			
	.001mm			

Remarks:5 increments, Gilson R, Sieve stack 1. MaryAnn 1. Vibe Table Standard Density.

Acceptance/Assurance Comparison

Acceptable Unacceptable QA Engineer/Designee

Date:

QA Review *Signature:*

Comments: *Date:*

17June22

Matt Culley *Date:*

NRML Supervisor

OVERSIZE CORRECTION WORKSHEET

State of Alaska DOT&PF Northern Region

ENGLISH

Project Name: Airport Way West Bicycle and Ped

Std. Density Lab #: AWW-BM(A)/SB(F)-SD-1

Max. Dry Density: 136.4 (Lb/ft^3)

Bulk SpG: 2.682

% Pass 3/4"	Corrected Density	% Pass 3/4"	Corrected Density
95	137.7	77	142.5
94	137.9	76	142.7
93	138.2	75	143.0
92	138.5	74	143.3
91	138.7	73	143.6
90	139.0	72	143.9
89	139.2	71	144.1
88	139.5	70	144.4
87	139.8	69	144.7
86	140.0	68	145.0
85	140.3	67	145.3
84	140.6	66	145.6
83	140.8	65	145.8
82	141.1	64	146.1
81	141.4	63	146.4
80	141.6	62	146.7
79	141.9	61	147.0
78	142.2	60	147.3

METRIC

Max. Dry Density: 2185 (Kg/m^3)

Bulk SpG: 2.682

% Pass 3/4"	Corrected Density	% Pass 3/4"	Corrected Density
95	2205.4	77	2282.2
94	2209.6	76	2286.6
93	2213.7	75	2291.1
92	2217.9	74	2295.5
91	2222.0	73	2300.0
90	2226.2	72	2304.5
89	2230.4	71	2309.0
88	2234.7	70	2313.6
87	2238.9	69	2318.1
86	2243.2	68	2322.7
85	2247.4	67	2327.2
84	2251.7	66	2331.8
83	2256.0	65	2336.5
82	2260.4	64	2341.1
81	2264.7	63	2345.8
80	2269.1	62	2350.4
79	2273.4	61	2355.1
78	2277.8	60	2359.8

*NOTE: Use 70% Corrected Density value for all values below 70%

Airport Way Subbase F Data

The following section presents the on-grade testing performed on the Airport Way Subbase F material.

<u>On-Grade Testing Results</u>

Figure E1 shows the deflection and elastic modulus values compared with the measured dry density during on-grade testing.

Figure E1. Subbase F On-Grade Testing and Dry Density Results

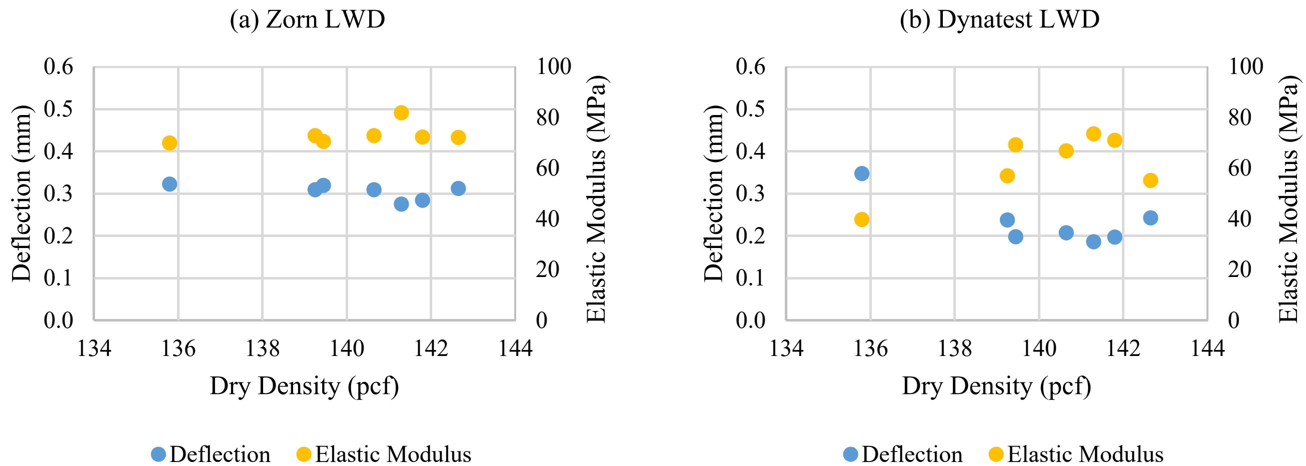


Figure E2 shows the deflection and elastic modulus values compared with the moisture content.

Figure E2. Subbase F On-Grade Testing and Moisture Content Results

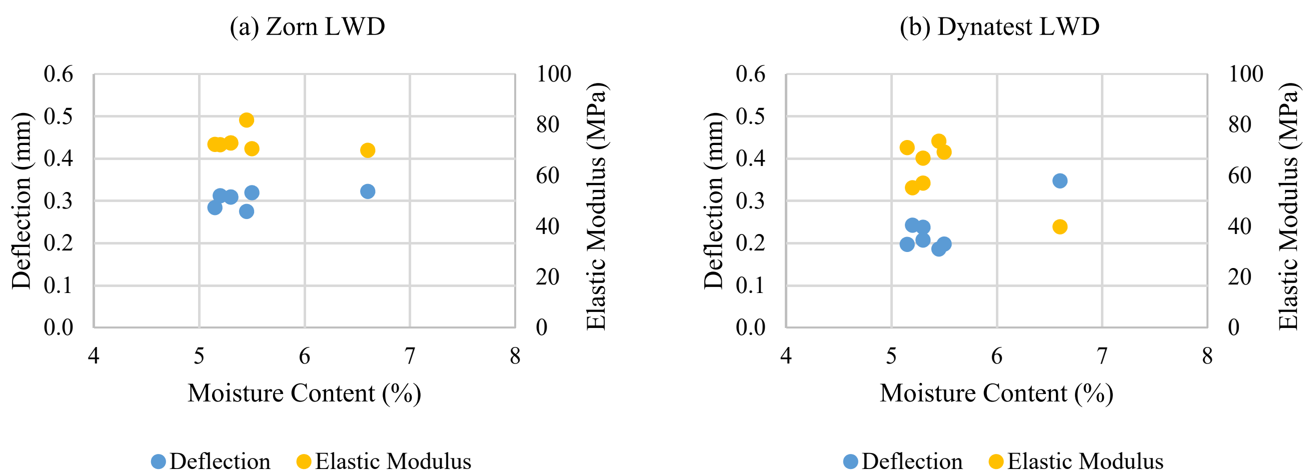


Table E1 shows the on-grade testing results for the Subbase F. On-grade results include dry density and moisture content measured by a nuclear moisture-density gauge, average elastic modulus and average deflection measured by each LWD model. The Borrow A material was sourced from the Exclusive Paving southside pit in Fairbanks.

Table E1. Subbase F On-Grade Testing Results

Test Number	Dry Density (pcf)	Moisture Content (%)	Zorn Average Elastic Modulus (MPa)	Dynatest Average Elastic Modulus (MPa)	Zorn Average Deflection (mm)	Dynatest Average Deflection (mm)
1	140.7	5.3	73	67	0.31	0.21
2	141.8	5.2	72	71	0.28	0.20
3	141.3	5.5	82	74	0.28	0.19
4	140.7	5.6	78	64	0.29	0.23
5	139.5	5.5	71	69	0.32	0.20
6	139.5	5.4	83	95	0.27	0.15
7	142.7	5.2	72	55	0.31	0.24
8	139.3	5.3	73	57	0.31	0.24
9	135.8	6.6	70	40	0.32	0.35

Appendix F – CASC

Standard Specifications for Airport Construction ITEM P-299 Aggregate Surface Course - CASC Material Specification

CASC Laboratory Test Results

CASC LWD Test Results

ITEM P-299 AGGREGATE SURFACE COURSE

DESCRIPTION

299-1.1 This item consists of an aggregate surface course composed of crushed or uncrushed coarse aggregate bonded with either soil or fine aggregate or both. It shall be constructed on a prepared course according to these Specifications and to the dimensions and typical cross section shown on the Plans.

MATERIALS

299-2.1 GENERAL. Aggregates shall consist of hard, durable particles or fragments of stone or gravel mixed or blended with sand, stone dust, or other similar binding or filler materials produced from approved sources. The aggregate shall be free from vegetation, lumps, or excessive amounts of clay and other objectionable substances. The coarse aggregate shall have a minimum degradation value of 45 when tested according to ATM 313. The aggregate shall have a percent of wear not more than 50 at 500 revolutions as determined by AASHTO T 96 and shall not show evidence of disintegration nor show loss greater than 12% when subjected to 5 cycles of sodium sulfate accelerated soundness test using AASHTO T 104.

a. **Crushed Aggregate Surface Course.** The aggregates shall consist of both fine and coarse fragments of crushed stone or crushed gravel mixed or blended with sand, screenings, or other similar approved materials. The material shall consist of hard, durable particles or fragments of stone and shall be free from excess soft or disintegrated pieces, dirt, or other objectionable matter.

The fractured particles in the finished product shall be as uniform as practicable. At least 75% by weight of material retained on the No. 4 sieve shall have one or more fractured faces, when tested according to ATM 305.

If necessary to meet this requirement, or to eliminate an excess of fine, uncrushed particles, the gravel shall be screened before crushing.

The fine, aggregate portion, defined as the portion passing the No. 4 sieve, produced in crushing operations, shall be incorporated in the base material to the extent permitted by the gradation requirements.

b. **Uncrushed Aggregate Surface Course.** This material may consist of natural pit-run aggregate. However, screening, blending, ripping, washing, and/or necessary mixing of the material or other processing may be necessary to meet the gradation and performance requirements of this specification.

299-2.2 GRADATION. The gradation of the uncrushed or crushed material shall meet the requirements of the gradations indicated in Table 1, when tested according to ATM 304.

TABLE 1
AGGREGATE GRADATION REQUIREMENTS

Sieve Designation(Square Openings)	Percentage by weight passing sieves For E-1
1.0 in.	100
3/4 in.	70-100
3/8 in.	50-85
No. 4	35-65
No. 8	20-50
No. 50	15-30
No. 200	8-15

SD

STATE OF ALASKA DOT & PF

ATM 304
WAQTC FOP for AASHTO T 27/T 11, METHOD C - FIELD WORKSHEET

[X] Acceptance [ ] Information

Sample No: Q-Sc-Ø- #1

Project Name: Ekwok Airport and New Stuyahok Airport Resurfacing

Federal No: AIP 3-02-0088-004-2021 / AIP 3-02-0193-004-2021 AKSAS No: CFAPT00292

Material: Surface course E-1 Source: Stock pile Ekwok village pit

Item No: P.299.020.0000 Location: Runway

Sta. / Sampled from: 116+80 Sampled by / Qual. No: Connor Prange # 121371

C/L & Grade Reference: R 20 Quantity Represented: 0-2000 ton Date: 7/2

FRACTURE — ATM 305 (WAQTC FOP for T 335)

[✓] Single Face [ ] Double Face [ ] All Face

Fractured Mass **F**	815.8	% Q = [Q / (F + Q + N)] x 100
Questionable Mass **Q**	—	* % Questionable ⇒
Unfractured Mass **N**	240.0	*Recount if > 15%
% Fracture	77.3%	⇐ [(F+(Q/2)) / (F+Q+N) x 100
Test by/date: CP 7/3	75%	⇐ Spec. (Minimum)

MOISTURE CONTENT — ATM 202 (WAQTC FOP for T 255/T 265)

			Constant Mass	
C	Container	2191.5	Time	Net Mass
A	Moist Mass + Container	13028.5		
Mw	Wet Mass **A – C**	10838.0	Overnight	
B	Dry Mass + Container	12346.0	Drying	
Md	Dry Mass **B – C**	10154.5		
W	**Moisture, %**	6.7%		

W = [(Mw – Md) / Md] x 100 ⇧ % Change ⇒

Test by/date: CP 7/3 % Change = [(Mp – Mn) / Mp] x 100

Mp = Previous Mass Measured / Mn = New Mass Measured

GRADATION — ATM 304 (WAQTC FOP for T 27 / T 11 – Method C)

mm / USC	Increment 1	Increment 2	Cumulative Mass Retained **CMR**	Reported % Retained = **(CMR / M)x100**	Rep'd % Pass. = 100 – Rep'd % Ret.	Specs.
100 / 4"						
*75 / 3"					t	
50 / 2"						
*37.5 / 1½"						
25 / 1"			Ø		100	100
*19.0 / 3/4"			137.0	1.3	~~98.7~~ 99	70 - 100
12.5 / 1/2"			1304.0	12.8	~~87.2~~ 87	
*9.5 / 3/8"			2356.5	23.2	~~76.8~~ 77	50 - 85
6.3 / 1/4"			—			
*4.75 / #4			4673.5	D 46.0	~~54.0~~ 54	35 - 65
Pan			5479.0	⇐ E	CA Check Sum (≤ 0.3%)	
Calc'd % Passing #4 = 100 – ((D / M) x 100)			53.977	⇐ F (0.001)	[(M – G) / M] x 100 = .019	
Dry Mass AFTER Sieving = (D + E)			10152.5	⇐ G		
Original Dry Mass BEFORE Sieving			10154.5	⇐ M	Test by/date: CP 7/3	

mm / USC	Cumulative Mass Retained C	Calc'd Cumulative % Retained R = (C / M_2) x 100	Calculated % Passing P = 100 – R	% Passing = (P x F) / 100	Specs.
*2.36 / #8	199.3	35.9%	64.1%	~~34.6%~~ 35	20 - 50
2.00 / #10	—				
*1.18 / #16	307.1	55.4%	44.6%	~~24.1%~~	24
*.600 / #30	359.8	64.9%	35.1%	~~18.9%~~	19
.425 / #40	—				
*.300 / #50	405.0	73.0%	27.0%	~~14.6%~~ 15	15 - 30
*.150 / #100	438.1	79.0%	21.0%	~~11.3%~~ 11	
.075 / #200	459.6	82.9%	17.1%	s 9.2%	8 - 15
Cum. Pan P	464.3	#200 on – 3" = [(s / t) x 100)] ⇒		~~N/A~~ 9.2	
H ⇒	464.5	⇐ Total Mass AFTER Wash		FA Check Sum (≤ 0.3%)	
M_2 ⇒	554.5	⇐ Total Mass BEFORE Wash		[(H – P) / H] x 100 = .04	
		Test by/date: CP 7/4			

LIQUID / PLASTIC LIMIT — ATM 204/205 (WAQTC FOP for T 89/T 90)

		LL	PL	
N	Number of Blows		X	
C	Container			
A	Moist Mass + Container	NON	-	
Mw	Moist Mass **A – C**	- PLASTIC		
B	Dry Mass + Container			
Md	Dry Mass **B – C**			
W	Moisture Content, % [(Mw — Md) / Md] x 100			
LL	W x $(N / 25)^{0.121}$		35 max.	LL Spec.
Test by/date: 7/3 CP	Plastic Index LL – PL		10 max.	PI Spec.

SPLITTER BIAS CHECK — ATM 303 (WAQTC FOP for T 248)

Splitter Pan #1 (Lesser Mass) → 100 – [——— X 100] = ——— (% bias) X
Splitter Pan #2 (Greater Mass) →

If the ratio of the two masses differs by more than 5%, corrective action must be taken.

FM ⇒			⇐ Fineness Modulus Target (From MD)
	to		⇐ FM Limits (± 0.2 of Mix Design FM)

(FM = Fineness Modulus = Total of % Retained of *Sieves / 100)

Remarks: Gradation, Fracture, Proctor, PL, LL

Signature / Date: Connor Prange 7/4

Checked by / Date: Steve Reed 7/14/22

Ekwok Airport CASC Data

The following sections present the on-grade testing performed on the Ekwok Airport CASC material.

On-Grade Testing Results

Figure F1 shows the deflection and elastic modulus values compared with the measured dry density during on-grade testing.

Figure F1. CASC On-Grade Testing and Dry Density Results

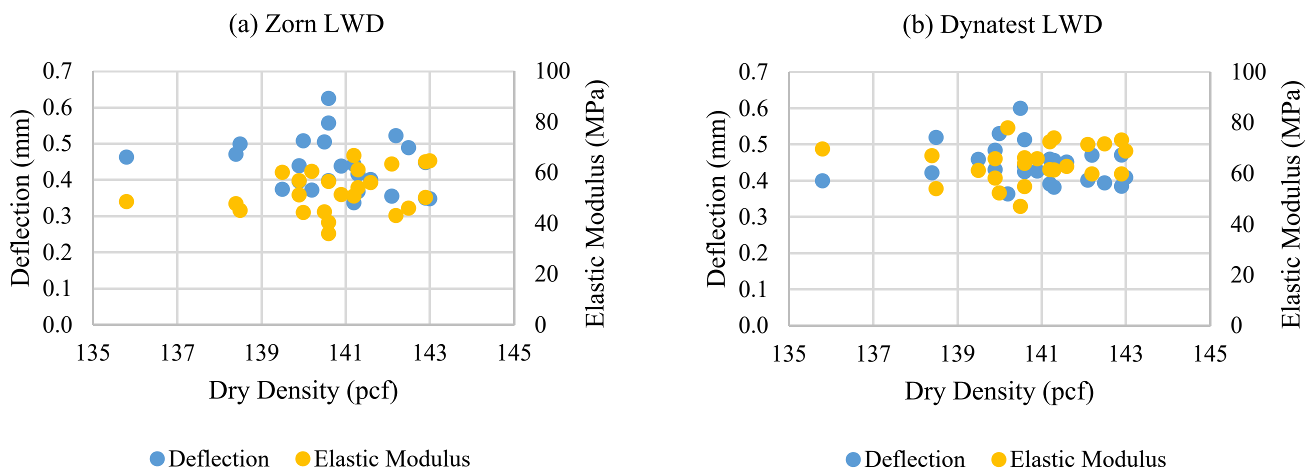


Figure F2 shows the deflection and elastic modulus values compared with the moisture content.

Figure F2. CASC On-Grade Testing and Dry Density Results

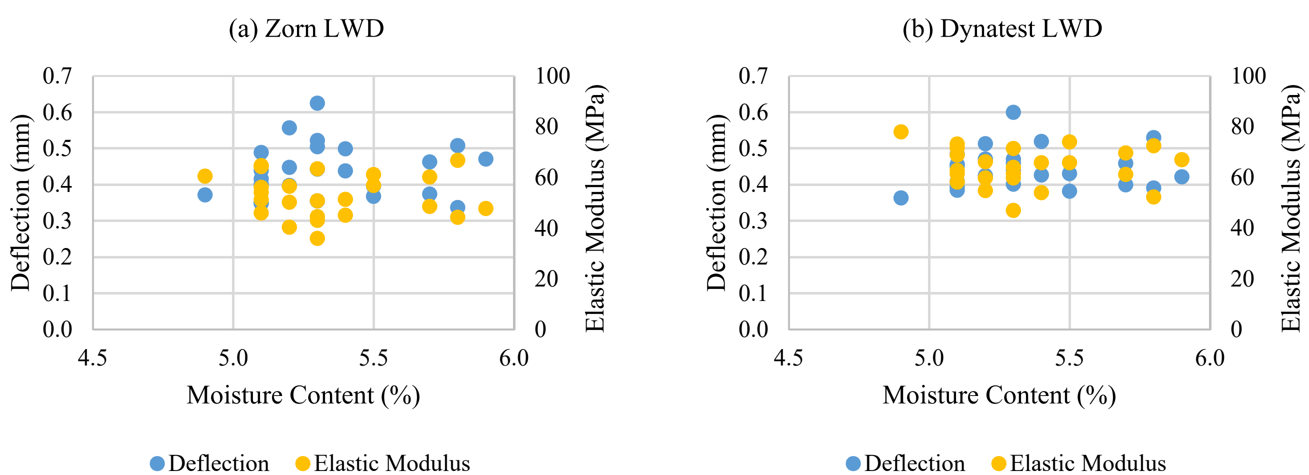


Table F1 shows the on-grade testing results for the CASC. On-grade results include dry density and moisture content measured by a nuclear moisture-density gauge, average elastic modulus and average deflection measured by each LWD model. The CASC material was sourced from the Ekwok Village pit in Ekwok.

Table F1. CASC On-Grade Testing Results

Test Number	Dry Density (pcf)	Moisture Content (%)	Zorn Average Elastic Modulus (MPa)	Dynatest Average Elastic Modulus (MPa)	Zorn Average Deflection (mm)	Dynatest Average Deflection (mm)
1	142.2	5.3	43	60	0.52	0.47
2	140.6	5.2	57	66	0.40	0.42
3	140.6	5.2	40	55	0.56	0.51
4	142.5	5.1	46	72	0.49	0.39
5	142.1	5.3	63	71	0.36	0.40
6	139.5	5.7	60	61	0.37	0.46
7	142.9	5.1	64	73	0.35	0.38
8	143.0	5.1	65	69	0.35	0.41
9	140.2	4.9	60	78	0.37	0.36
10	141.2	5.8	67	73	0.34	0.39
11	138.5	5.4	45	54	0.50	0.52
12	141.6	5.1	56	63	0.40	0.45
13	141.3	5.5	61	74	0.37	0.38
14	139.9	5.1	51	58	0.44	0.48
15	139.9	5.5	57	66	0.40	0.43
16	140.6	5.3	36	64	0.63	0.44
17	142.9	5.2	50	60	0.45	0.47
18	141.2	5.3	51	62	0.44	0.46
19	140.0	5.8	44	52	0.51	0.53
20	135.8	5.7	49	70	0.46	0.40
21	140.9	5.4	51	66	0.44	0.43
22	138.4	5.9	48	67	0.47	0.42
23	141.3	5.1	54	61	0.42	0.46
24	140.5	5.3	45	47	0.51	0.60

Appendix G – Reporting Forms

LWD Control Strip Reporting Form

LWD Field Acceptance Reporting Form

Preliminary LWD Laboratory Reporting Form

STATE OF ALASKA
DOT & PF

RELATIVE LWD DEFLECTION by the CONTROL STRIP METHOD

ATM 310 - FIELD WORKSHEET

☐ Acceptance ☐ Verification ☐ Info. ☐ IA ☐ QC **Sample No:**

Project Name:

Federal No: AKSAS No:

Material: Source:

Item No: LWD Model: LWD S/N:

Station to Station: Lane: Width:

Date:

**All initial deflection readings are the average of the 3 measurement drops at that location*

Equipment	Pass #:	*Location 1	*Location 2	*Location 3	Average	Change	Remarks / MC(%)
Drum Roller	1					---	
Roller Brand:	2						
Model No:	3						
Frequency (VPM):	4						
Amplitude:	5						
Pneumatic Roller	1					---	
	2						
	3						
	4						
	5						

Locations ⇒	1	2	3	4	5	6	7	8	9	10	LWD-TV
Deflection 1											
Deflection 2											
Deflection 3											
Average Deflection											

MOISTURE CONTENT - *Use WAQTC FOP for T 255/T 265*

Wet Mass + Tare											**Average Moisture (%)**
Dry Mass + Tare											
Mass of Tare											
% Moisture											

Remarks:

Tested By / Qualification No:

Signature / Date:

Checked by / Date:

STATE OF ALASKA
DOT & PF

LWD ACCEPTANCE TESTS

ATM 310 - FIELD WORKSHEET

☐ Acceptance ☐ Verification ☐ Info. ☐ IA ☐ QC

Page No: ______ / ______

Project Name: ______

Federal No: ______ AKSAS No: ______

Material: ______ Source: ______

Item No: ______ LWD Model: ______ LWD S/N: ______

Date: ______

TARGET VALUES - *All Values Determined by Control Strip Method - Acceptable MC Range ±2% of Average MC*

Control Strip No: ______ LWD-TV: ______ Average % MC: ______

ON-GRADE DEFLECTION TEST MEASUREMENTS - *All DTMs are the average of the three measurement drops at that location*

Test #	Station/Location	Deflection 1	Deflection 2	Deflection 3	Average	In-Situ MC
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						

Remarks: ______

Tested By / Qualification No: ______

Signature / Date: ______

Checked By / Date: ______

HDL Engineering Consultants

Preliminary LWD Laboratory Reporting Form

PROJECT NAME:	LWD for QA	TEST METHOD:	ASTM D-1557
CLIENT JOB NO:	HFHWY00274	MOLD DIAMETER:	inches
HDL PROJECT NO:	22-112	MOLD VOLUME:	cubic feet
CLIENT:	DOT&PF	SPECIFIC GRAVITY:	2.75 (assumed)
		MAX. DRY DENSITY:	PCF
ATTENTION:		ASTM D4718 CORR:	PCF
		OPTIMUM MC:	
SAMPLE NO:		CORRECTED MC:	
SAMPLE LOCATION:		DATE TESTED:	
		TESTED BY:	
DESCRIPTION:		REVIEWED BY:	

COMPACTION TRIAL NO.	1	2	3	4	5
Weight of Mold & Wet Soil - g (B)					
Weight of Mold - g (C)					
Weight of Wet Soil - g (D)=(B-C)					
Wet Density of Soil - lb/ft^3 (E)=(D/A)/453.6					

MOISTURE CONTENT TARE NO.					
Weight of Wet Soil & Tare - g (F)					
Weight of Dry Soil & Tare - g (G)					
Weight of Tare - g (H)					
Weight of Dry Soil - g (I)=(G-H)					
Weight of Moisture - g (J)=(F-G)					

MOISTURE CONTENT - % (K)-J/I*100					
DRY DENSITY - lb/ft^3 (L)=E/(K/100+1)					
LWD Modulus Value					

Acceptable Moisture Content Range - %	
Max Lab Dry Density - lb/ft^3	
Assumed Poisson Ratio (from AASHTO TP 123-01)	
Target modulus values for desired field plate size	
LWD device type	
LWD drop weight	
LWD plate diameter	
LWD Drop heights	

REMARKS:

Appendix H – Training Materials

Training Checklist

Training Presentation

LWD Material Checklist

LWD unit

- Plate
- Rod and 10 kg weight
- Recording device (phone or included handheld device)
- Connecting cable for recording device (if required)
- Charger or extra batteries

Field book and reporting forms

Writing utensil

Moisture content measurement device and tools

Bags and/or buckets for sampling material when required

LWD Quick Start Checklist

Remove LWD from case and assemble (see manufacturer's instructions and the LWD Set-Up Diagram for specific details)

Select testing location

Prepare surface for testing at selected location, including leveling surface, filling voids, removing debris, etc.

Perform 3 seating drops (do not need to record these drops)

Turn on recording device

Create/Select PROJECT NAME and create/select LOCATION NAME in recording device

Start recording device and perform 3 measurement drops

Record results on reporting forms (measurements should also automatically be saved in the recording device)

Repeat at additional locations as appropriate

LWD Quick Tips

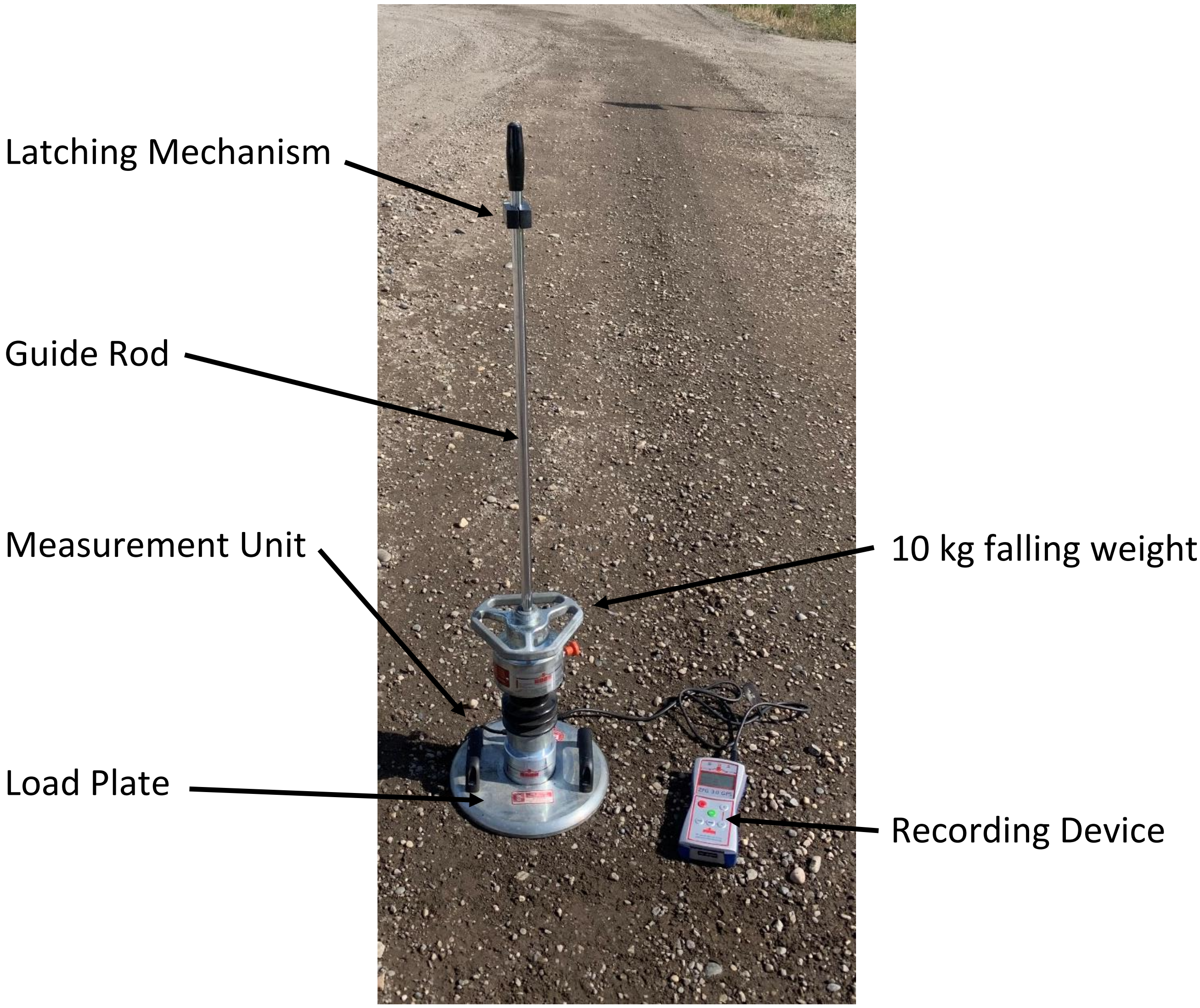
Ensure the surface beneath the plate is flat and free of debris including wires that connect to the device.

Use a consistent naming scheme for each test location on a project. This will make it easier to go back and reference your tests in the future.

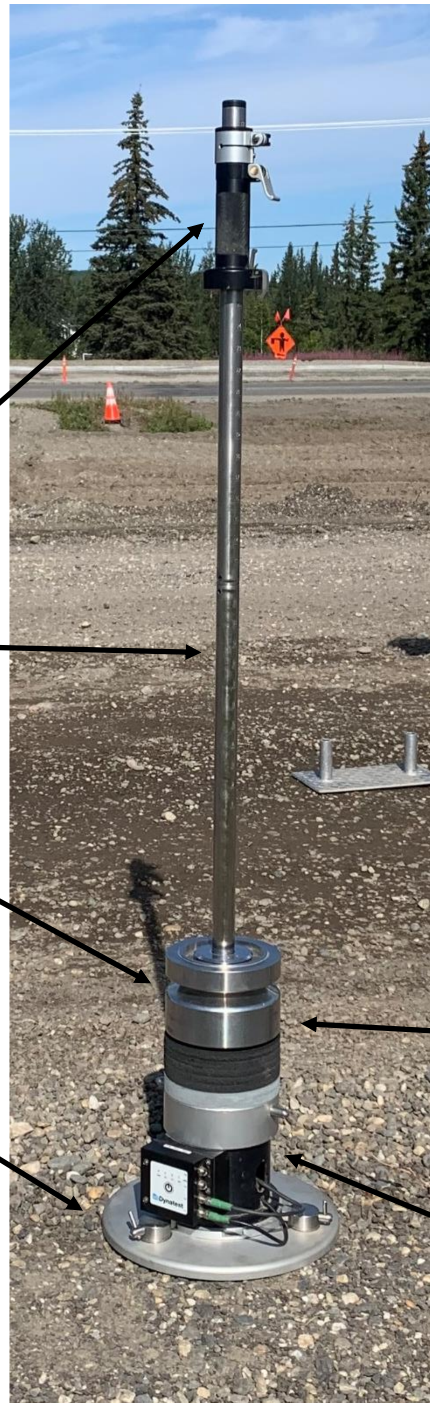
Perform seating drops without recording. If you do record the seating drops, remove the data from the record and redo the test.

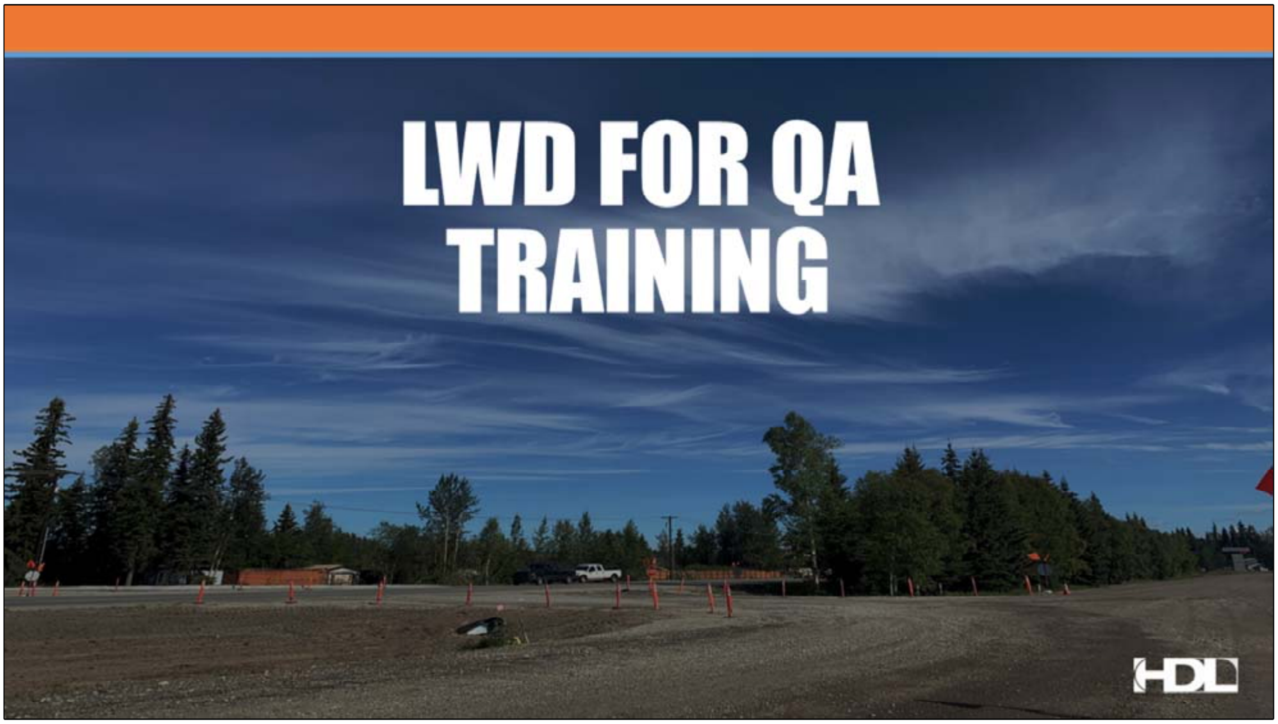
If using the Zorn LWD, you must catch the weight on the first rebound. Otherwise, the test is invalid and will need to be redone.

Zorn LWD Set-Up Diagrams



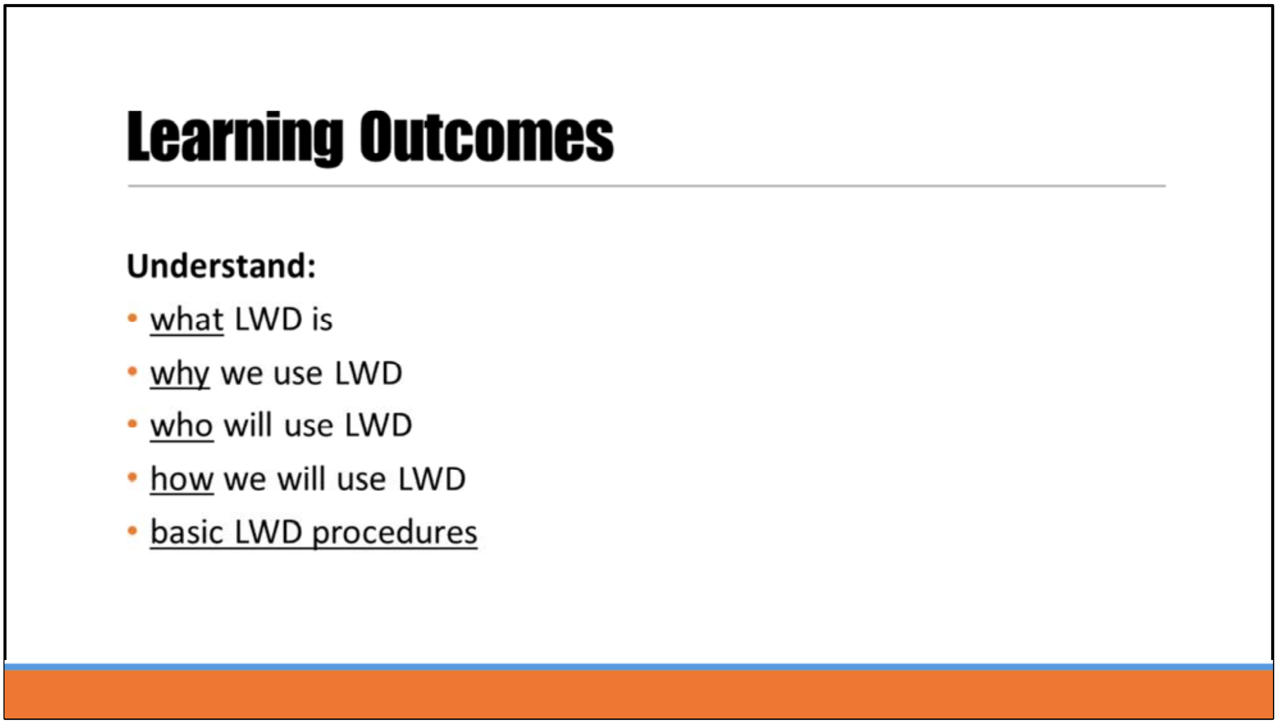
Dynatest LWD Set-Up Diagrams




LWD FOR QA
TRAINING

Acknowledgement

HDL Engineering Consultants, LLC developed the following training materials as part of the project HFHWY00274 LWD for QA of Compacted Sublayers and Earthwork.



The basic learning outcomes that we hope you come away from this training presentation with include:

- What is LWD?
- Why is DOT&PF using LWD?
- Who at DOT&PF will be using and/or interacting with LWD and its results?
- How is DOT&PF using LWD?

We also hope that you will gain a basic understanding of the LWD practices and procedures that the DOT&PF is implementing for construction Quality Assurance.

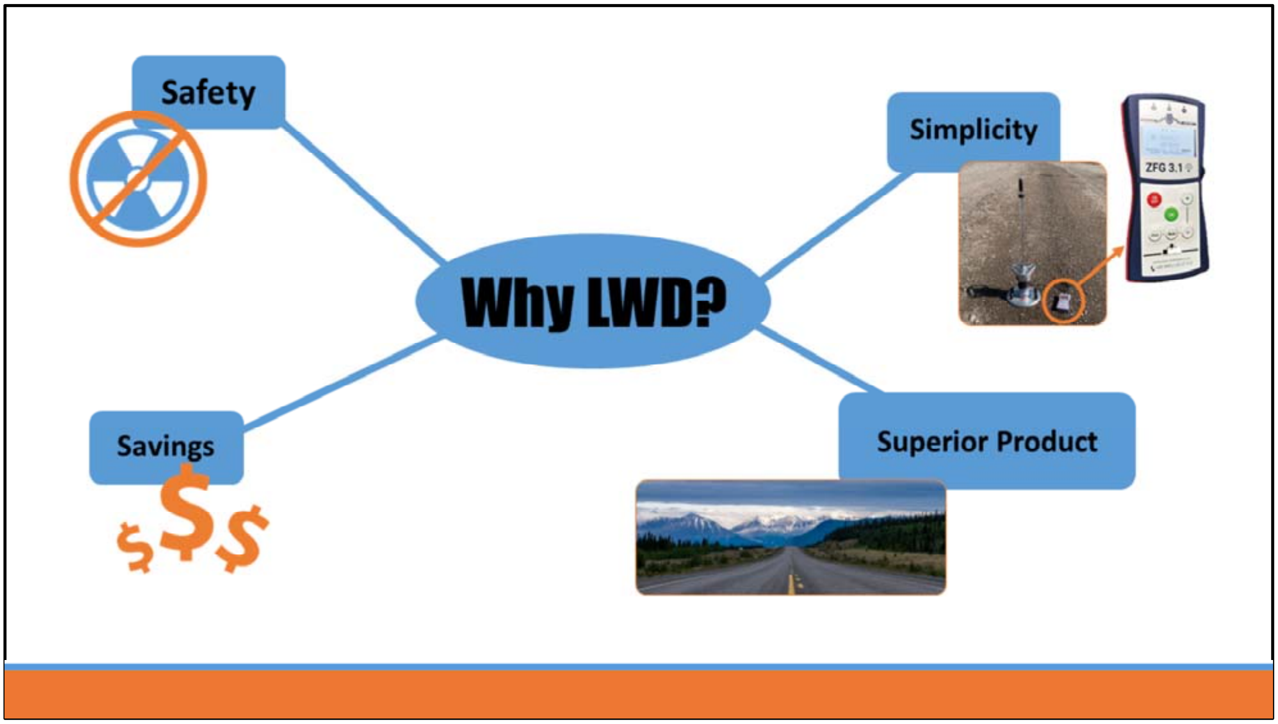
What is LWD?

LWD is…

- A device that drops a 10 kg weight from a predetermined height and measures and records deflection.
- A lower deflection means a better performing material.

ZORN LWD

LWD stands for Lightweight Deflectometer. It is a tool for evaluating strength properties (stiffness and modulus) of unbound soils and aggregates. There are currently three different models of LWD devices. DOT&PF and their consultants have tested two models of LWD. The Zorn LWD is the model that DOT has chosen to pursue at this time. The basic premise of an LWD is to drop a weight from a predetermined height and measure the deflection in order to determine the stiffness or elastic modulus of the material.



The main reason DOT&PF is moving toward embankment acceptance by LWD is that it provides a direct measurement of Strength, the fundamental embankment property used for design. Nuclear gauges measure density, which has almost no correlation to strength. Only 34% of highway embankments in Iowa that were accepted by conformance to density standards met Design Strength. Additional reasons include: increased technician safety by reducing risk of potential radiation exposure, increased cost savings, and ultimately a better quality product (road or airport runway) over the design life.

Who already uses LWD?

- Minnesota
- Indiana
- Iowa
- Nebraska
- Maryland

The Minnesota and Indiana DOT's already use LWD almost exclusively for their construction QA testing. Iowa, Nebraska, and Maryland are all in various parts of the process to implement LWD methods into their QA testing.

Who will be using LWD?

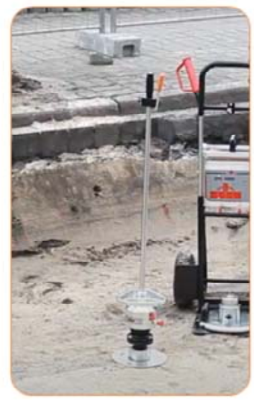
DOT Employees

Consultants

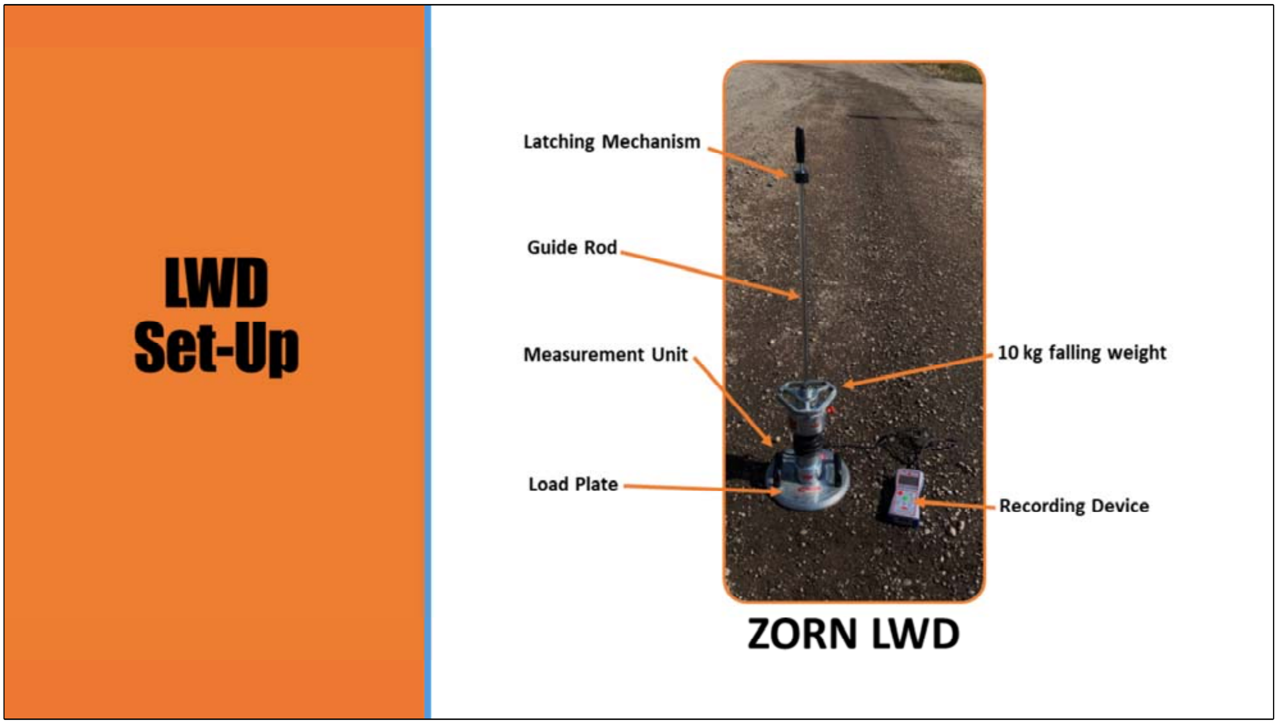
Contractors

Over the next 2-5 years nuclear gauges will be phased out and replaced by light weight deflectometers. DOT&PF rovers and materials technicians will be using the LWD devices for embankment acceptance and quality assurance in the field. Consultant staff contracted to manage construction of DOT&PF projects will also begin using LWD devices.

How will we use LWD?



LWD will be used as an alternative to nuclear density gauges for acceptance and QA of unbound soils and aggregates. Currently the DOT uses maximum dry density from proctor/ vibe table laboratory testing to determine the target density values for compaction. Near future policies and procedures will use LWD for acceptance and quality assurance of unbound soils and aggregates.



The basic LWD set-up consists of the following components, a load plate, measuring device, 10 kg falling weight, guide rod, latching mechanism, and recording device. The picture shown on this slide shows how a properly set-up Zorn LWD unit should look.

LWD Basic Operation

1. Select the testing location
2. Prepare the roadway's surface for testing at the selected location, including leveling the surface, filling voids, removing debris, etc.
3. Perform 3 seating drops (do not need to record these drops)
4. Turn on the recording device
5. Create/Select *[PROJECT NAME]* and create/select *[LOCATION NAME]* in the recording device
6. Start the recording device and perform 3 measurement drops
7. Record results in field book/reporting forms (measurements should also automatically be saved in the recording device)
8. Repeat at additional locations as required

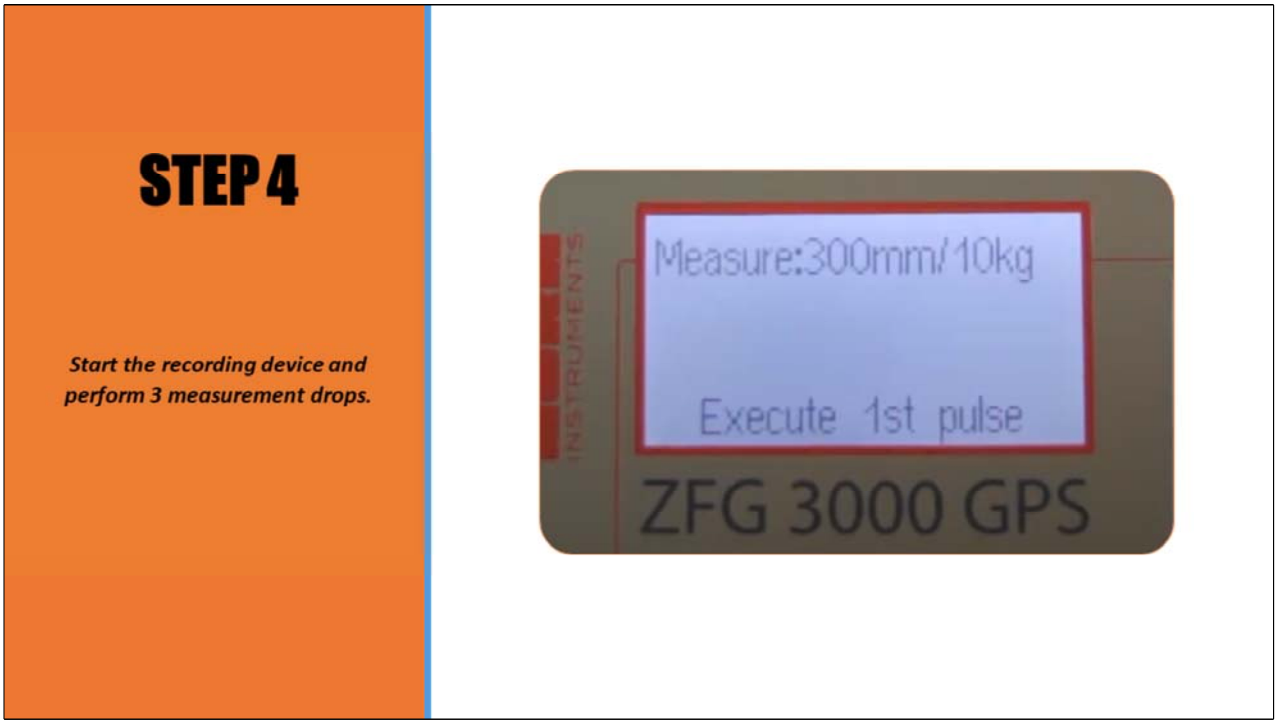
Select the testing location. These locations can be marked with paint, stakes, etc or they can be located by the technician at the time of the test. Make sure that the testing locations are meeting the requirements in the project specifications. If the surface is not level, be sure to add some fine to medium sand at the testing location to ensure good contact between the surface and the load plate. This procedure is very similar to the procedure you are all already used to doing during ATM 309.

STEP 2

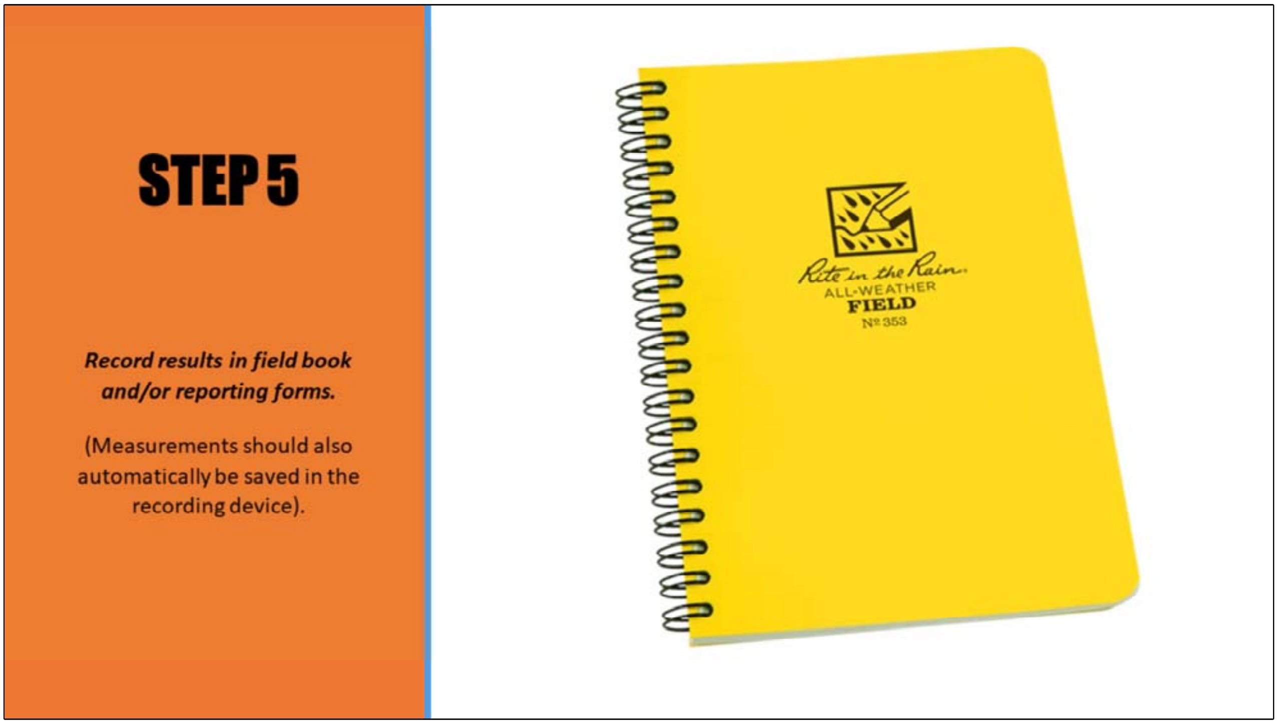
Perform 3 seating drops (do <u>not</u> need to record these drops).

Perform the three seating drops. These should not be recorded and can be performed before the recording device is turned on or attached.

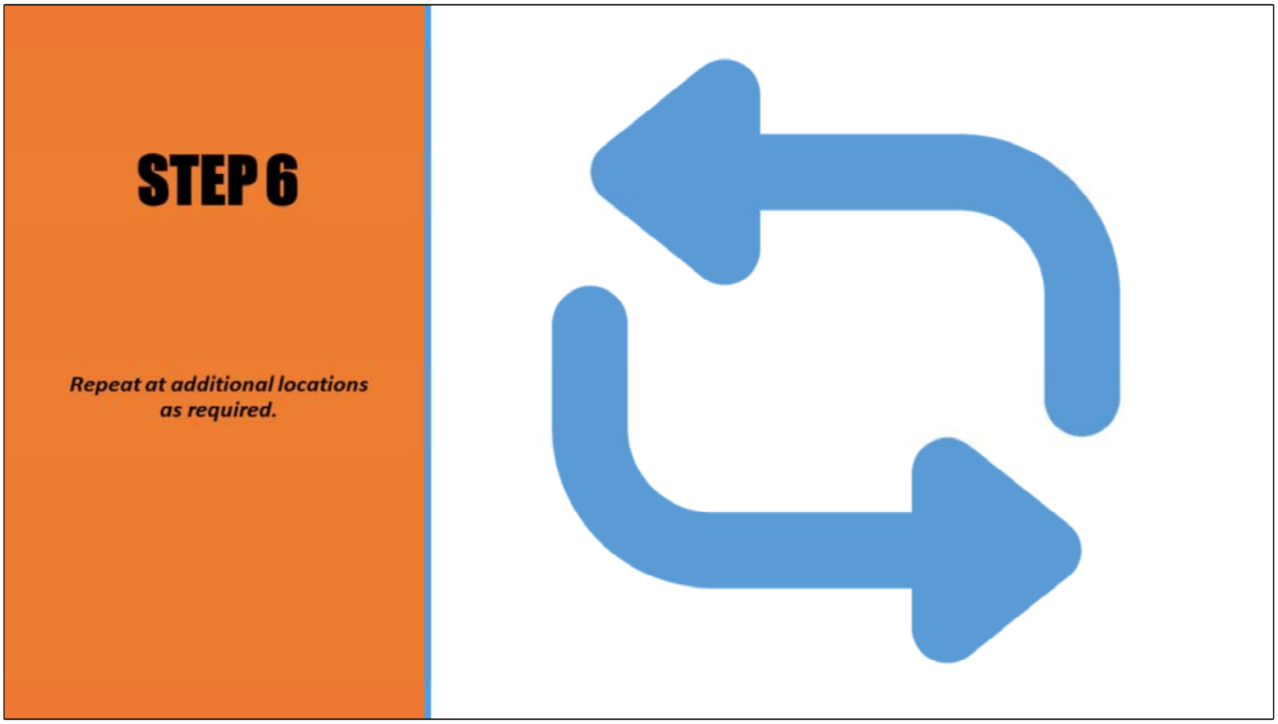
Once the seating drops are performed, turn on the recording device and enter the naming. Start with the project name and then the location. The project name will only need to be entered once, but a location name will need to be created at each new testing location. Use a consistent naming convention so it is easy to reference the data with specific testing locations. Setting up the project name and location name can be done in the office or field beforehand.



After selecting the correct project and location, begin recording and perform the three measurement drops. If using a Zorn LWD, the weight must be caught on the first rebound after each drop, otherwise the test is invalid and must be repeated. The recording device will tell you when it is ready for the weight to be dropped after the three drops, it will give you a readout of the results and save the results for later. On some models, a paper “receipt” can be printed after each test.



The measurements should be recorded on the correct reporting form. Make sure to have a field book and reporting forms available during testing.



Repeat the testing at additional locations as required. The number and frequency of testing is generally included in the project specifications.

Reporting Forms

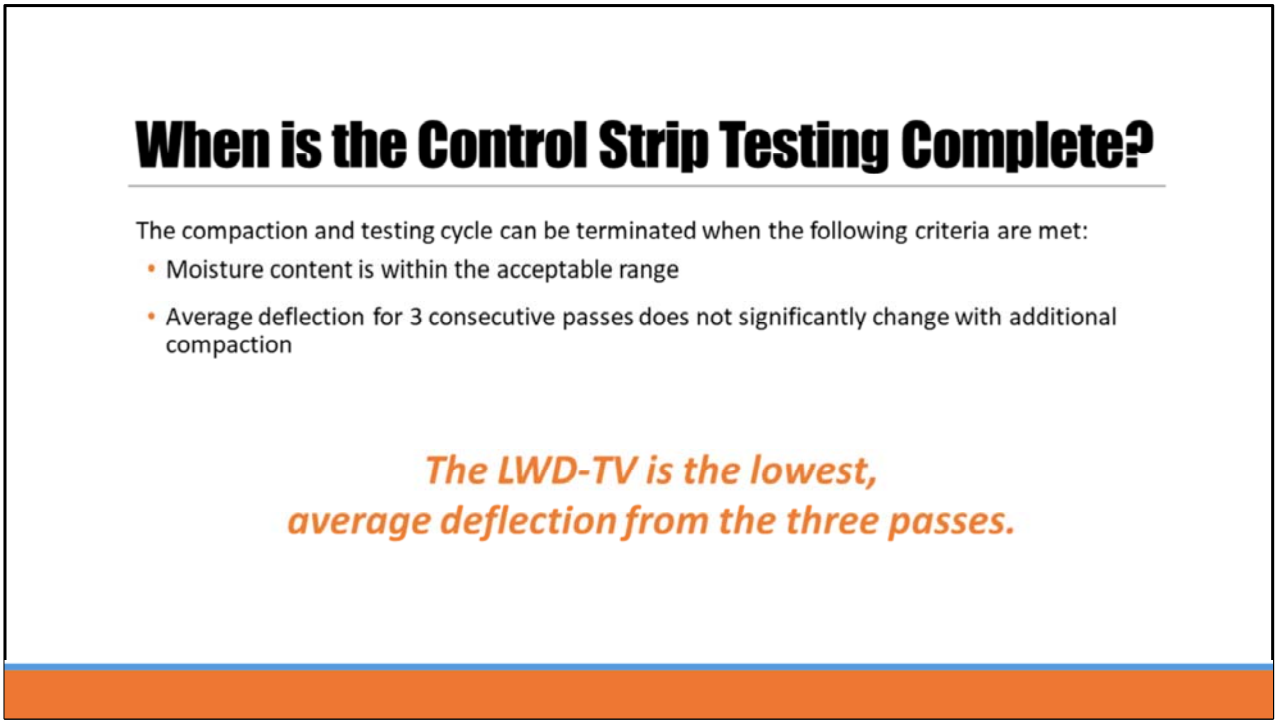
- Control Strip Testing Form
- Acceptance Testing Form

At this time, we will pass out the LWD reporting forms. Discuss what the reporting forms are used for (control strip testing and on grade acceptance testing) and explain how to fill the forms out.

The target values (LWD-TV) will ultimately be used for acceptance of compacted material (similar process to what is used currently with the nuclear density gauges in ATM 309). Currently, DOT&PF is planning to use a control strip method for determining target values. This ATM will look very similar to ATM 309 for those of you that are familiar with that test method. The main difference comes from utilizing an LWD instead of a nuclear density gauge. The target value will be determined for every material on a project, this includes materials of the same spec (aka P-299), but from different sources. The calibration area method for determining the target values will be discussed in the next slide.

Control Strip Testing Procedure

- **Construct the control strip** to the specified dimensions (typically 200 feet by 12 feet)
- **Establish target moisture content** based on the Project Engineer's prior experience and expertise with the materials in the region.
- **Sample material from the control strip** before and after compaction for grain size comparison in the future if needed.
- **Select and mark the test locations.** These locations will remain the same after each consecutive roller pass.
  1. At least 20 feet apart
  2. At least 3 test locations per roller pass
- **Begin testing** at selected locations a minimum of 2 roller passes at selected locations before you believe desired deflections will be reached.
- After starting LWD testing, **complete additional testing** at each location after each subsequent roller pass.



The initial LWD-TV noted here is the LWD-TV from the control strip testing locations. To obtain the LWD-TV that will be used to compare with the Deflection Test Measurement for acceptance, an additional step is required. Just like in ATM 309, after the desired compaction has been achieved, 10 locations within the control strip should be randomly selected and tested using the same LWD procedure described above (and utilized during the control strip testing).

LWD-TV Calculation

$$LWD - TV = \frac{(D_1 + D_2 + D_3 + D_4 + D_5 + D_6 + D_7 + D_8 + D_9 + D_{10})}{10}$$

Where:

LWD-TV = Target Value Deflection

D_n = average deflection for random test at location n

This is the calculation to determine the LWD-TV. It is just a basic average formula. The LWD-TV that you get from this equation is the one that will be used to compare with the Deflection Test Measurement to determine a passing or failing test.

When to perform Control Strip Testing?

A new LWD-TV is needed when:

- The first time a specific material is used on a project
- If there has been a significant change in the materials (gradation, source, etc.)
- More than 20% of the Deflection Test Measurements are ≤0.6*LWD-TV
- Failing results consistently occur, and adequate compaction effort and moisture conditions are observed

These are several of the cases where a control strip test will be warranted/ required. Obviously, you need to do one every time a new material is introduced to a project in order to get your required values for QA. The other cases generally refer to when a retest of an already tested material needs to occur due to changes in materials and/or repeatedly failing tests.

Minimum Acceptance Testing Frequencies

Refer to the project Material Sampling & Testing Frequency (MSTF) table and the project specifications.

The minimum acceptance testing requirements can be found in the specifications and the project MSTF table.

Passing Versus Failing?

*Deflection Test Measurement ≤ 1.2*LWD-TV*

A passing test is when the LWD-TV is greater than the Deflection Test Measurement. In other words, when the deflection measured at a location is less than the LWD-TV (determined by ATM 310 – the calibration area method), then the material is passing in that location. As a reminder, just like you are used to, the plans and specs for a specific project will give you the testing frequency, etc which will determine how many tests you need to take on each material, etc.

Moisture content testing guidelines can be found in the following locations: ATM 310, the project MSTF table, and the specifications. Refer to these documents to determine when and how often to test for moisture content on your project.

Picture above is the Ohaus moisture analyzer and a traditional microwave, both are acceptable ways to determine the MC according to ATM 310.

LWD Tips

- **Ensure the surface beneath the plate is flat and free of debris**, including wires that connect to the device.
- **Use a consistent naming scheme** for each test location on a project. This will make it easier to go back and reference your tests in the future.
- **Perform seating drops without recording**. If you do record the seating drops, remove the data from the record and redo the test.
- If using the Zorn LWD, you must **catch the weight on the first rebound**. Otherwise, the test is invalid and will need to be redone.

Here are a few tips that we have learned the hard way though our experiences using the LWD.

QUESTIONS?