TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): ____Maryland Department of Transportation____________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(285)*	Transportation Pooled Fund Program - Report Period: □Quarter 1 (January 1 – March 31, 2014) □Quarter 2 (April 1 – June 30, 2014) □Quarter 3 (July 1 – September 30, 2014) □Quarter 4 (October 1 – December 31, 2014) □Quarter 5 (January 1 – March 31, 2015) □Quarter 6 (April 1 – June 30, 2015) □Quarter 7 (July 1 – September 30, 2015) □Quarter 8 (October 1 – December 31, 2015) ■Quarter 9 (January 1 – March 31, 2016)

Project Title:
Standardizing Lightweight Deflectometer Measurements for QA and Modulus Determination in Unbound Bases and Subgrades

Name of Project Manager(s): Rodney Wynn	Phone Number: 443-572-5043	E-Mail RWynn@sha.state.md.us
Lead Agency Project ID: TPF-5(285)	Other Project ID (i.e., contract #):	Project Start Date: January/15/2014
Original Project End Date: December/31/2015	Current Project End Date: July/15/2016	Number of Extensions: 1

Project schedule status:
□ On schedule ■ On revised schedule □ Ahead of schedule □ Behind schedule

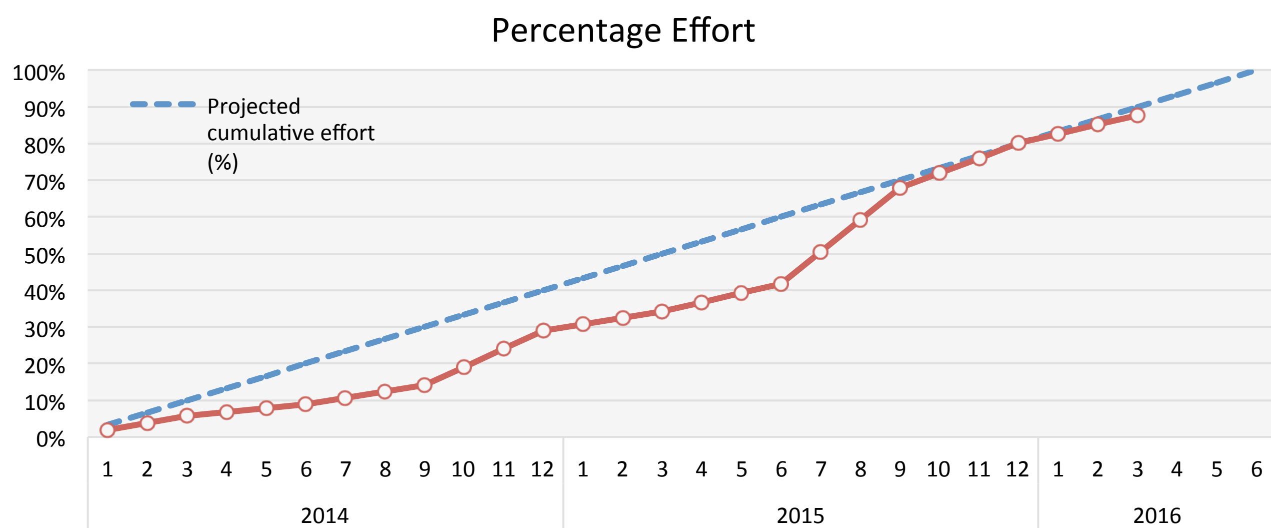
Overall Project Statistics:

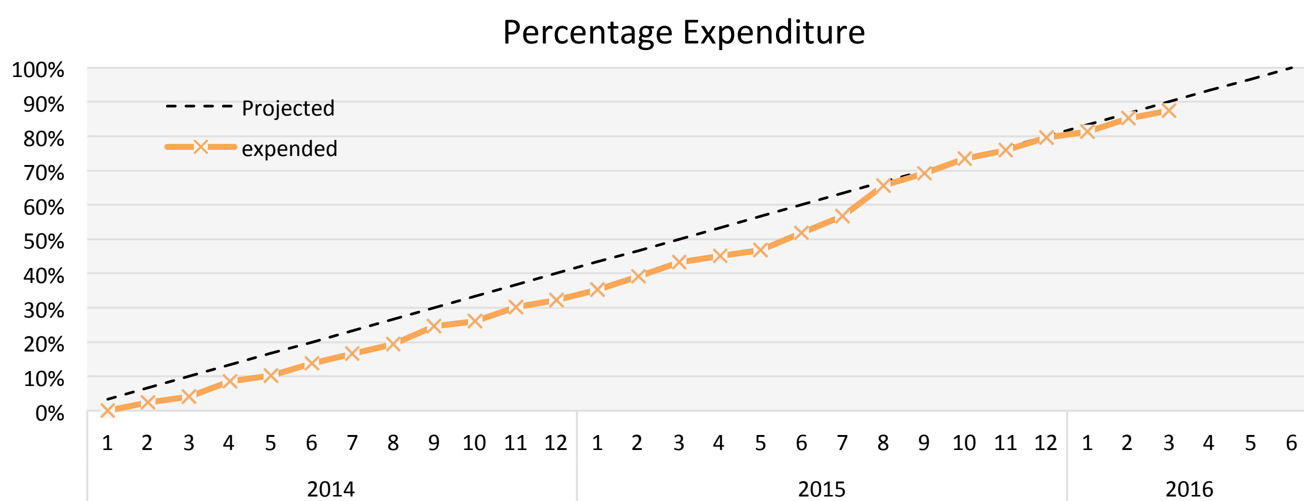
Total Project Budget	Total Cost to Date for Project	Percentage of Work Completed to Date
$371,984.00	$325,438.58	87.5%

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date
$29,322.18 7.9%	$37,198.40	88%

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):





The progress with respect to each Task is as followed:

Literature Review. Percent completion of Task 1: 100%

The personnel continue the review of the current and upcoming literature when deemed necessary.

Project personnel participating in these activities: Schwartz, Khosravifar, Afsharikia.

Equipment Evaluation. Percent completion of Task 2: 100%

During this reporting period, the Zorn LWD's deflection sensor was replaced and recalibrated and the Olson LWD was recalibrated and modified to be able to apply less pressure on lower drop heights on the mold. Our evaluation of these two LWD devices for testing on the mold are as follows:

- Olson LWD:
  - Difficult to change the drop height
  - Heavy plate
  - Impossible to use the designed collar (Figure 44) for wet samples
  - Changing the gains introduces complexities
  - Cannot delete an individual drop without deleting the whole set of 6 drops (this option is available for Dynatest LWD)
- Zorn LWD:
  - Very heavy plate
  - Not possible to change the drop height
  - Applied force must be assumed for lower drop heights

The Dynatest LWD annular plug option was also investigated. This and our overall evaluation of the Dynatest LWD are detailed in Appendix B.

Project personnel participating in these activities: Schwartz, Afsharikia, Khosravifar.

Model Refinement/Development. Percentage completion of Task 3: 92%

Several of the models in Task 3 were refined in conjunction with laboratory efforts in Task 4, specifically the laboratory resilient modulus testing and LWD testing on the Proctor mold.

Project personnel participating in these activities: Schwartz, Afsharikia, Khosravifar.

Controlled Trials. Percentage completion of Task 4: 100%

This task was completed during the previous quarter. The LWD Proctor mold testing in Task 5 were also compared to the field data from Task 4.

Project personnel participating in these activities: Schwartz, Khosravifar, Afsharikia.

Field Validation. Percentage completion of Task 5: 88%

Extensive LWD testing on Proctor molds has been performed to determine the target modulus. Most of the data have been analyzed and visualized. The target moduli were compared to the field-measured moduli to assess compaction quality.

Project personnel participating in these activities: Schwartz, Afsharikia, Khosravifar.

Draft Test Specifications. Percentage completion of Task 6: 27%

Development of a practical field testing protocol has been a learning process. Testing on several subgrades validated the LWD testing on Proctor mold method. Additional model refinement is needed to provide a comprehensive approach that combines stress, moisture dependency, and spatial variability in the field. A representative subgrade example is provided in Appendix A. Some issues of the laboratory testing set up to find the target moduli were addressed for eventual inclusion in the final specification; these are described in Appendix B. Future testing will be conducted using the recommended protocol.

Project personnel participating in these activities: Schwartz, Afsharikia, Khosravifar.

Workshop and Final Report. Percentage completion of Task 7: 57%

Progress was made during this reporting period on documenting the results from LWD testing on Proctor mold for the field test sites.

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Anticipated work next quarter:

- Continuing on LWD Proctor mold testing under the new recommended condition using Zorn, Dynatest, and Olson LWDs
- LWD Proctor mold testing for GAB material and incorporating the effect of finite layer thickness
- Finalizing and improving the LWD testing on Proctor mold procedure
- Completing the soil drying analysis. This is a parametric study of the factors affecting the drying rate
- Laboratory resilient modulus testing on the soil samples from the field test sites, as required
- Continued drafting the Final Report.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

Potential Implementation:

LWDs should be implemented more widely using standardized testing procedures and data interpretation methods. LWDs are a tools for performance based construction quality assurance testing that not only result in a better product but also provide the quantitative measures critical to better understanding the connection between pavement design and long term pavement performance. As the benefits of performance based quality assurance testing become increasingly apparent, more public agencies and private consultants are expected to acquire these tools and implement the standardized procedures. The product of this research will allow state DOT construction specifications to be modified to include this new lightweight deflectometer (LWD) option for construction quality assurance.

Appendix A

LWD Testing on Proctor Mold for Subgrade Soils

Introduction

Proctor molds were compacted at 3 to 7 different moisture contents using standard compaction energy (AASHTO T-99). Depending on the subgrade gradation, either 4 inch or 6 inch molds are used. LWD tests were performed directly on the compacted molds sitting on the laboratory's concrete foundation (Figure 1). The diameter of the LWD plate is almost equal to mold diameter, so the plate clears the rim of the mold and measures the deflection on top of the compacted soil inside. Full height drops on the Proctor mold exert stress levels well in excess of conditions in the field, so reduced height drops are used to permit interpolation/extrapolation to the field stress state. Six drops at each drop heights were performed. The drop heights for each LWD are listed in Table 1. The maximum deformation (δ), and maximum impact load (F), and maximum peak stiffness (k) equal to F/δ were averaged for the last three drops and used in the analysis.

Figure 1- Zorn, Olson and Dynatest LWDs on 6 inch Proctor molds.

Table 1- Drop heights for LWD testing on Proctor molds.

LWD type	Drop Heights [inches]					
Zorn	1	2	3	4	5	12.5
Dynatest	1	2	3	4	5	7
Olson	1	2	3	4	5	8.5

The modulus of the soil was derived from the theory of elasticity for a cylinder of elastic material with constrained lateral movement as imposed by the rigid mold (Figure 2). The analyses assume that the soil is an elastic material, that the deformations occur in the soil material only and not in the underlying stiff concrete foundation, and that dynamic effects can be neglected.

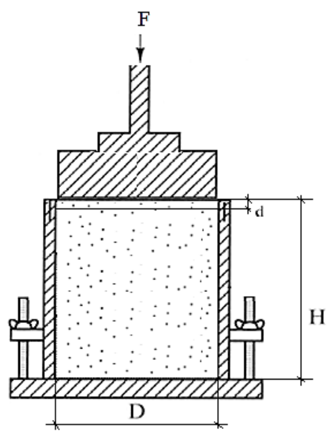

Figure 2- Schematic of LWD testing on Proctor mold. (Tefa, 2015).

The relevant equation from the theory of elasticity is as follows:

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

Where:
μ = Poisson's ratio
H = height of the mold
D = the diameter of the plate or mold
k = soil stiffness =F/δ as calculated by LWD device

During the field validation phase, LWD tests were performed on 9 subgrade soils using all three 3 devices. Density and moisture measurements were also made at each station in the field in order to compare the LWD results with the Percent Compaction. Table 2 summarizes the subgrade locations, soil identification codes used in presenting the results, soil classification, and comments on the field conditions.

Table 2- Subgrade Soil Inventory.

	Soil Description	Code	AASHTO	Unified		Field LWD Testing Condition Remarks
1	Lynchburg, VA Subgrade	Lynchburg SG	A-3	SP-SM	Poorly graded sand with silt	Subgrade placed and compacted 2 days before LWD testing performed (Dried SG)
2	Maryland Route 5 Waste Contaminated Embankment	MD5_1 SG	A-1-a	SW	Well graded sand with gravel	Tested right after compaction, Soil was waste contaminated, no compaction requirements for the embankment in the field
3	Maryland Route 5 Subgrade	MD5_2 SG	A-2-7	SP	Poorly graded sand with gravel	Tested right after compaction, well compacted
4	Albany, New York Embankment	NY SG	A-3	SP	Poorly graded sand	Tested right after compaction
5	Indiana cement modified Subgrade	IN SG+ Cement	A-2-4	SW-SM	Well graded sand with silt and gravel	Tested a week after placement and compaction (Dried and cured SG), No NDG data available
6	Missouri Subgrade	MO SG	A-3	SP	Poorly graded sand with gravel	No LWD data available, Testing only on compacted GAB on top of SG
7	Maryland route 404 sand on top of compacted Subgrade	MD404 top SG	A-2-7	SP	Poorly graded sand	1 to 2 inches of dry sand placed on top of wet compacted local subgrade, tested right after compaction
8	Maryland route 404 Subgrade	MD404 bottom SG	A-2-6	SP	Poorly graded sand	
9	Jacksonville ,Florida Subgrade	FL SG	A-2-7	SP	Poorly graded sand	Subgrade placed and compacted few days before LWD testing performed (Dried SG)

In order the investigate the applicability of LWD testing directly on the Proctor mold to determine the target modulus, the MD Route 5 Subgrade (MD5_2 SG), a well compacted poorly graded sand with gravel constructed on top of an embankment, was used as a reference. Testing of this subgrade was performed immediately after compaction and at one hour and two hours after compaction (total of 3 rounds of testing). This procedure was subsequently applied to the other subgrades that were tested immediately after compaction. The full set of results will be presented in the final report.

LWD testing on the Proctor mold is an easy add-on to the convention Proctor test in order to determine the target LWD modulus in field. The LWD modulus on the mold is derived from Equation 1 and is designated as *E_ZM*, *E_DM*, and *E_OM* for the Zorn, Dynatest, and Olson LWDs, respectively.

For subgrades, the field modulus is calculated using the Bousinesq half-space equation assuming the subgrade to be a linear elastic, isotropic, homogeneous semi-infinite continuum:

$$E = \frac{2k_s\left(1-\upsilon^2\right)}{Ar_0}$$

Equation 2

in which $k_s = \left|\frac{F_{peak}}{w_{peak}}\right|$, A is the stress distribution factor obtained from

Each drop height corresponds to a different normalized applied plate pressure P/Pa, where Pa is atmospheric pressure. After calculating the modulus at each drop height and moisture content (MC), a two variable regression analysis was performed to find the E_xM as a function of MC and P/Pa, keeping in mind that the dry density (DD) and MC should remain within the acceptable range specified by the State's specification for density based compaction control. Data points with DD less than 95% of Standard Proctor Maximum Dry Density (MDD) were excluded from the regression analyses. This would happen automatically in most cases when excluding data points at less/more than 2% difference in MC from the Optimum Moisture Content (OMC). The target modulus is then determined from the regression equation at the field MC and P/Pa. The ratio of the field-measured modulus to the calculated target modulus (E_field/E_target) is compared to Percent Compaction (%PC) as obtained from a conventional Nuclear Density Gauge (NDG) to validate the method. The field measurements from the different LWD devices are also compared.

Table 3 , ν is Poisson's ratio (assumed to be 0.35 for all soils in this report), and r_0 is the plate radius. The stress distribution shape was assumed to be uniform for sandy soils with or without gravel, giving $A=\pi$ (
Each drop height corresponds to a different normalized applied plate pressure P/Pa, where Pa is atmospheric pressure. After calculating the modulus at each drop height and moisture content (MC), a two variable regression analysis was performed to find the E_xM as a function of MC and P/Pa, keeping in mind that the dry density (DD) and MC should remain within the acceptable range specified by the State's specification for density based compaction control. Data points with DD less than 95% of Standard Proctor Maximum Dry Density (MDD) were excluded from the regression analyses. This would happen automatically in most cases when excluding data points at less/more than 2% difference in MC from the Optimum Moisture Content (OMC). The target modulus is then determined from the regression equation at the field MC and P/Pa. The ratio of the field-measured modulus to the calculated target modulus (E_field/E_target) is compared to Percent Compaction (%PC) as obtained from a conventional Nuclear Density Gauge (NDG) to validate the method. The field measurements from the different LWD devices are also compared.

Table 3). The peak deflection (w_{peak}) and applied load (F_{peak}) were taken as the average of the last three LWD drops in the field. A 300mm plate size was used for all three LWDs in the field.

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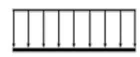
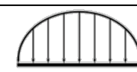
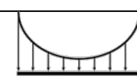
Table 3- Stress distribution factor for different soil types (Terzaghi, Peck and Mesri, 1996)

Soil type	**Factor (A)**	**Stress distribution Shape**
Uniform (mixed soil)	π	
Granular material (parabolic)	$3\pi/4$	
Cohesive (inverse-parabolic)	4	

Maryland Route 5 Subgrade

Three rounds of LWD and NDG tests were conducted at one-hour intervals on the freshly compacted sloped subgrade on top of an embankment as shown in Figure 3. There were a total of 10 stations spaced at 10 foot intervals. The embankment beneath the subgrade was a waste contaminated soil containing plastic, glass, metals, cloth, tires, and other deleterious materials.

Figure 3- Maryland Route 5 LWD testing on Sloped Subgrade.

The NDG readings were made using direct transmission mode at a depth of 6 inches. The subgrade had a slope of about 2 degrees. At the first station, the subgrade thickness to the waste contaminated embankment was about 3 feet. The subgrade became thinner at the end stationsto the point where the NDG readings for the last few stations cannot be trusted.

Figure 4 shows the gradation for the poorly graded sand with gravel subgrade. Moisture samples were collected from the top 3 inches at each station at each round and were sealed in zip-lock bags for subsequent oven drying in the lab. Figure 5 compares the MC measurements from the NDG and oven dried methods. Disregarding the last 4 stations at which the NDG reading were affected by waste contaminated embankment soil, a difference of up to 1% can be observed between the MC measured by the NDG and oven drying methods. This variance is particularly noticeable in 2nd and 3rd rounds when the soil surface becomes slightly drier than at the 6 inch depth.

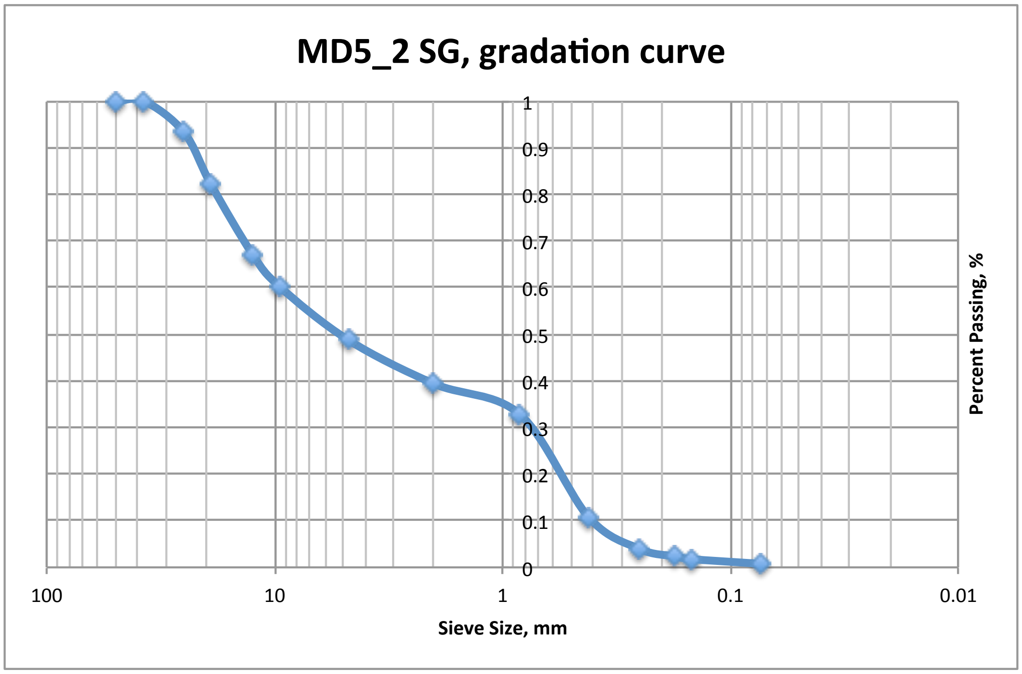


Figure 4- Maryland Route 5 gradation.

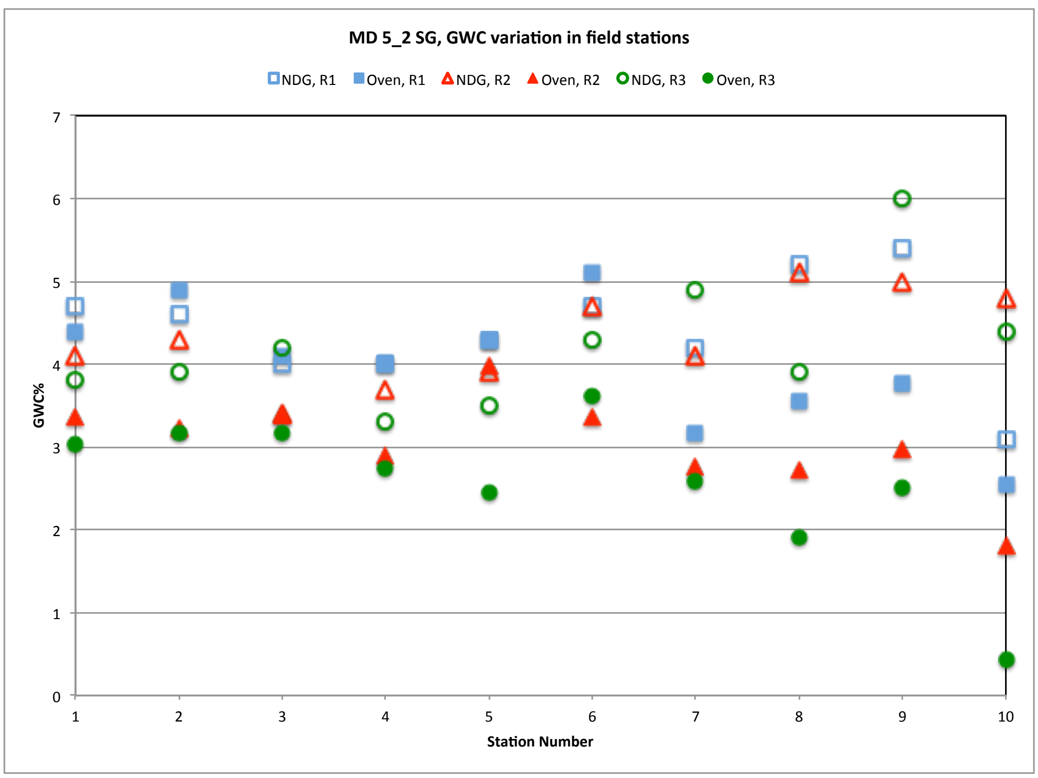


Figure 5- NDG and oven-dried MC measurements at each station for 3 rounds.

Figure 6 presents the Percent Compaction (PC) levels at each station as measured by the NDG. PC% does not change over time for the first 6 stations. This is sensible as it is the ratio of field DD to MDD and the DD does not change with drying. The inconsistency in the results for the last 4 stations confirms that the subgrade was too thin and that the NDG measurements were being influenced by the underlying embankment layer.

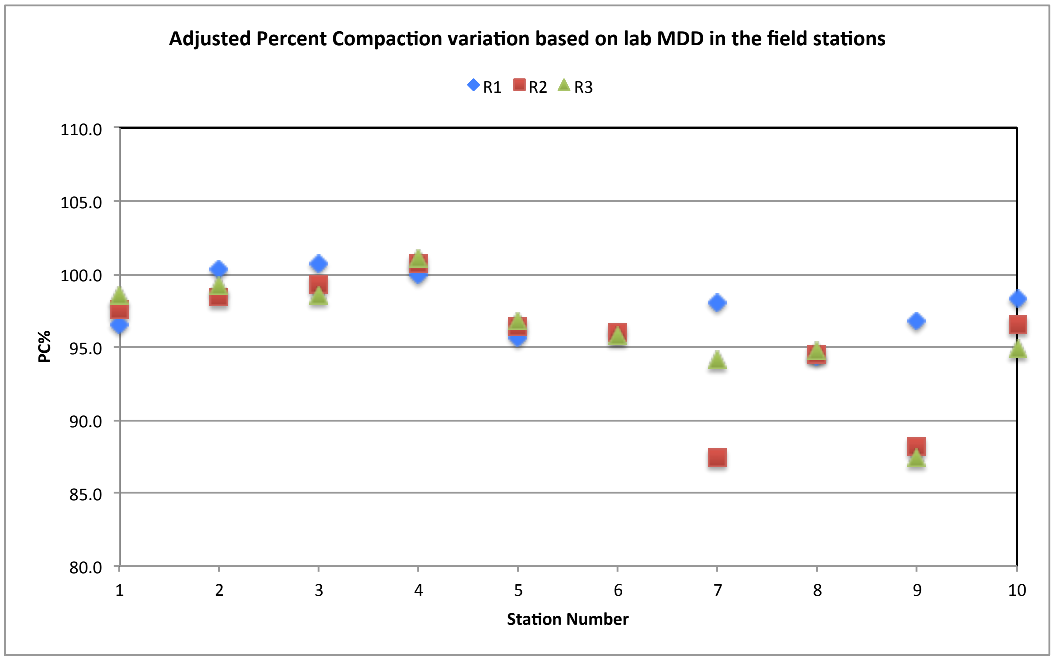


Figure 6- Percent compaction measured by NDG at each station for 3 rounds.

Proctor molds were compacted according to AASHTO T-99 at different MC values. The LWD moduli on the 6 inch diameter mold were plotted versus Gravimetric Water Content (GWC) for the different stress states (P/Pa) and then superimposed on the compaction curve of DD versus GWC for each LWD. These results are shown in Figure 7, Figure 8, and Figure 9. The graph legend shows the P/Pa values for the different heights shown in Table 1.

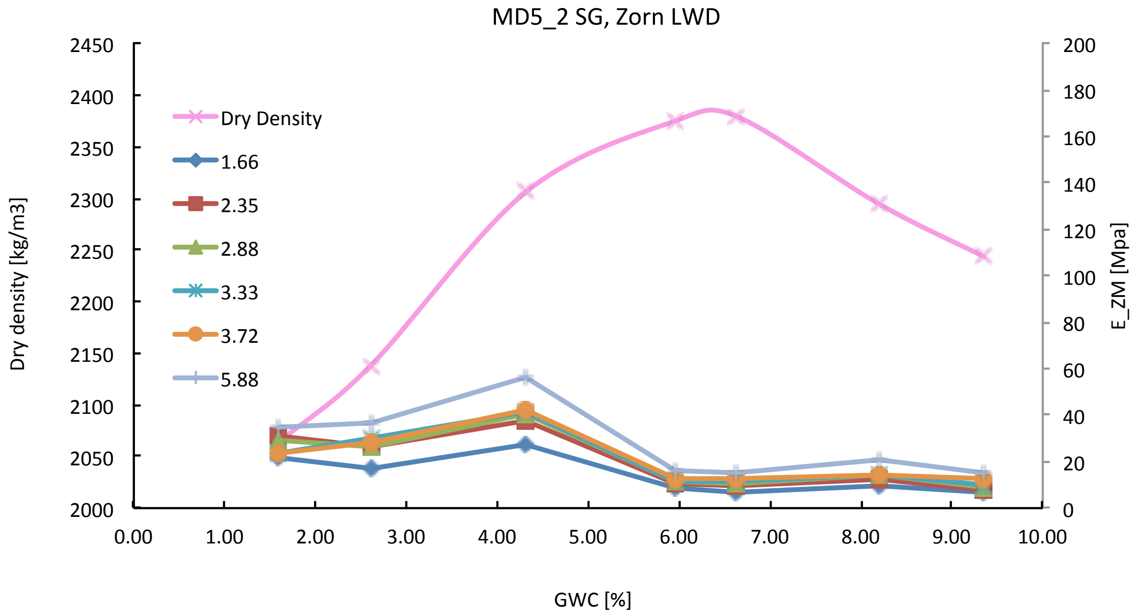


Figure 7- Zorn LWD modulus on Proctor mold for different stress states (P/Pa) and Dry Density versus GWC.

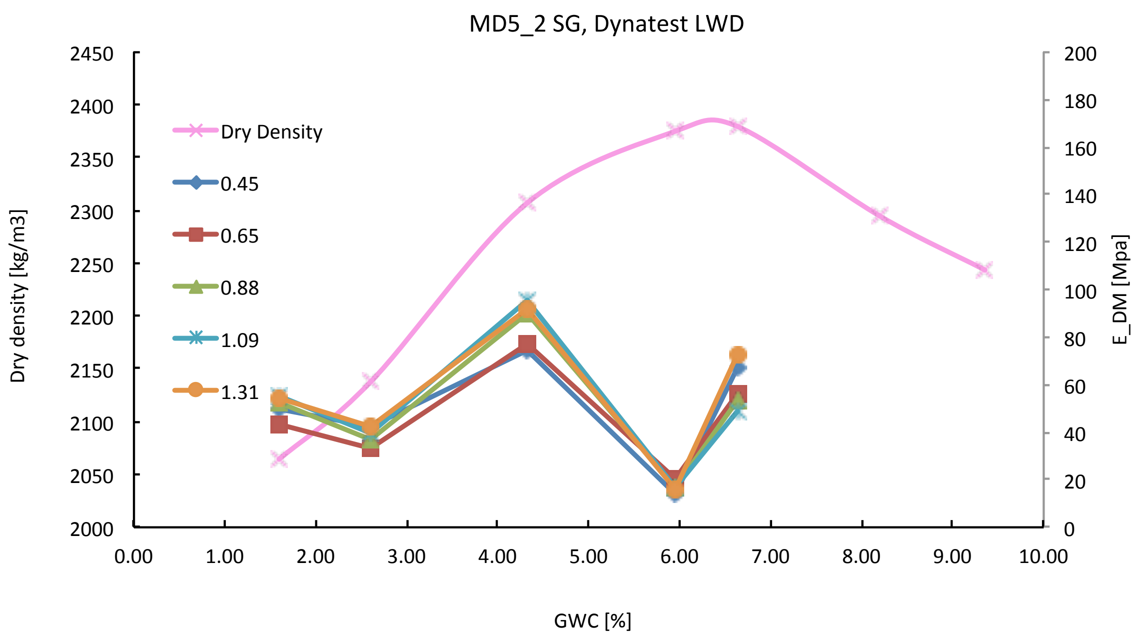


Figure 8- Dynatest LWD modulus on Proctor mold for different stress states (P/Pa) and Dry Density versus GWC.

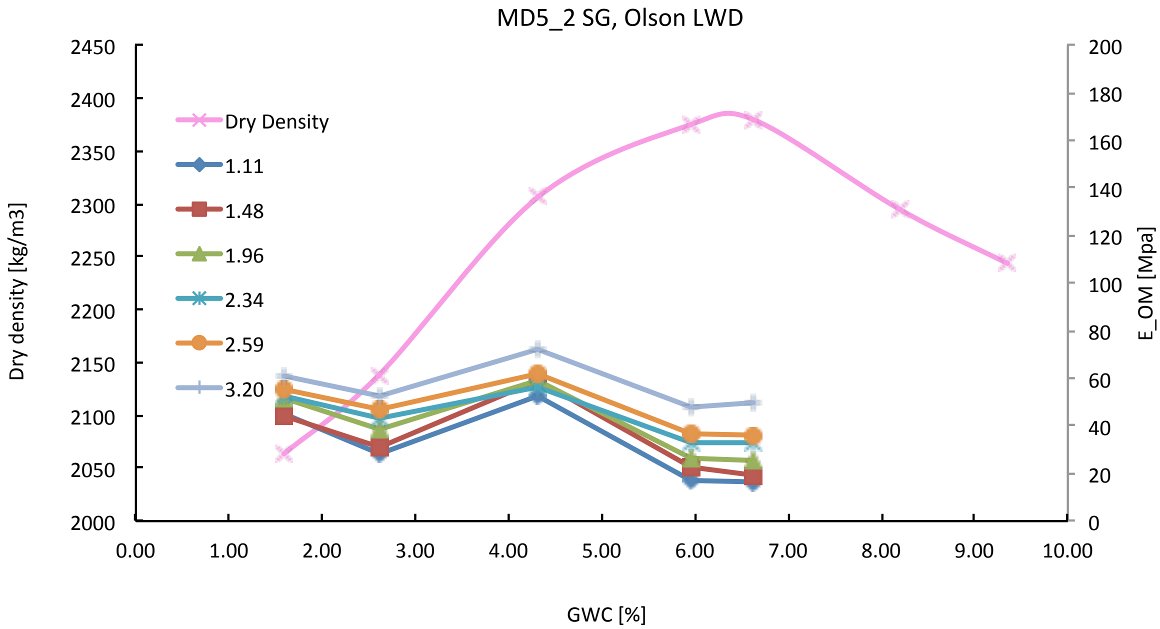


Figure 9- Olson LWD modulus on Proctor mold for different stress states (P/Pa) and Dry Density versus GWC.

The tests captured the stress and moisture dependency trends of the soil behavior. It should be noted that the field conditions are mostly on the dry side of optimum or at optimum MC. Requiring that quality assurance testing be performed immediately after compaction to avoid environmental effects like precipitation or excessive drying means that field soils should not be more than +1% of OMC. LWD testing on molds at moisture conditions far wet of OMC is simply impossible. Depending on soil type, even OMC+2% may be too wet for LWD testing. Tests at high MC values exhibit much permanent deformation, uneven deformations under LWD plate, and water drainage from the top and bottom of the mold during testing. This is discussed further in Appendix B.

The sample-to-sample variability and the variability of the moduli values in last three drops were higher for the laboratory testing data than in the field data. One of the reasons could be the physical instability of the test setup, especially from higher drop heights, and permanent deformation and damage in the samples due to multiple drops from the 3 LWDs. Attempts were made to solve this instability issue to improve the quality of data captured on the mold. These are described in Appendix B.

The Dynatest LWD results (Figure 8) on wet side of optimum did not follow the expected trends observed with other LWDs. The modulus increased with increasing GWC from 6% to 7%. This could be a result of measuring the deflection directly on top of the wet soil that may bulge into the annular void. This can be prevented by using the Dynatest LWD's Plugin optional feature

(Figure 10). The Plugin closes the central annulus so that the center geophone measures plate deflection instead of soil deflection. This is also described further in Appendix B.

Figure 10- Measuring deflection directly on top of soil versus plate deflection using Plugin with Dynatest LWD

The plate pressure P is calculated by dividing the applied load by the LWD plate area. For the testing in this study, a 300mm diameter plate was used for field testing and 100 or 150 mm diameter plates for lab LWD drops on the 4 or 6 inch diameter molds, respectively. The load at each drop height is a direct output from the Dynatest and Olson LWDs since they are equipped with a load cell. The applied load for Zorn LWD is calibrated at 7.07 kN for full height and is estimated for the reduced drop heights assuming the magnitude of the peak load varies with $h^{0.5}$.

From the two variable regression analyses, the target modulus can be estimated using the field MC and P/Pa at each station. The ratio of the field-measured modulus to the calculated target modulus (E_field/E_target) is presented in Figure 11, Figure 12, and Figure 13. The results are color coded for each round of testing: R1 is immediately after placement, R2 is one hour after placement, and R3 is two hours after placement. The field to target modulus ratio is greater than 1 for almost all stations for all 3 LWD types. There is a jump in the ratio from station 6 on; this is where the subgrade layer begins to thin and the influence of the dried embankment layer below interferes with the results. Little effect of drying is observed after each round for the Zorn and Olson LWD results. However, the Dynatest LWD results exhibit a slight increase in field modulus and thus E_field/E_target. This maybe due to Dynatest's center geophone, which measures deflection directly on top of the soil through annulus plate; this may make it more sensitive to any drying occurring at the soil surface.

Excluding the last five stations where the underlying embankment corrupts the results, the E_field/E_target is compared to Percent Compaction (PC) in Figure 14, Figure 15, and Figure

16. Values in the upper right corner of the graph are in acceptable zone, meaning that acceptable compaction of more than 95% has achieved and the corresponding E_field/E_target is greater than 1 (target modulus passed). The MD Route 5 Subgrade was well compacted and passed both the modulus and density compaction quality control criteria.

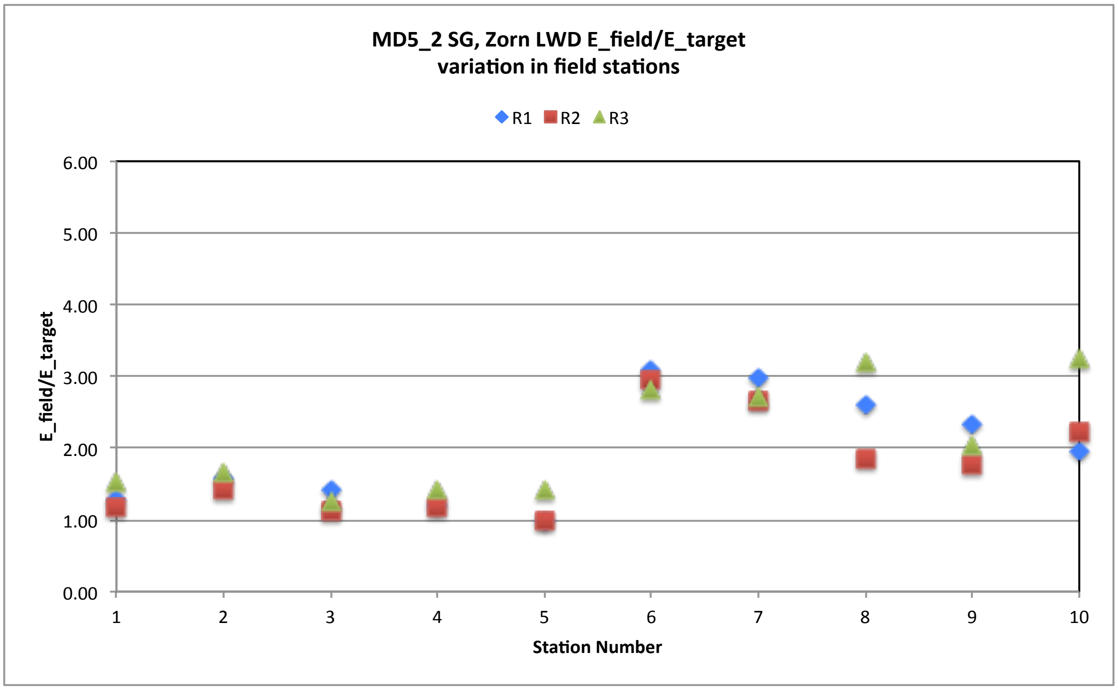


Figure 11- Measured field modulus to calculated target modulus ratio: Zorn LWD.

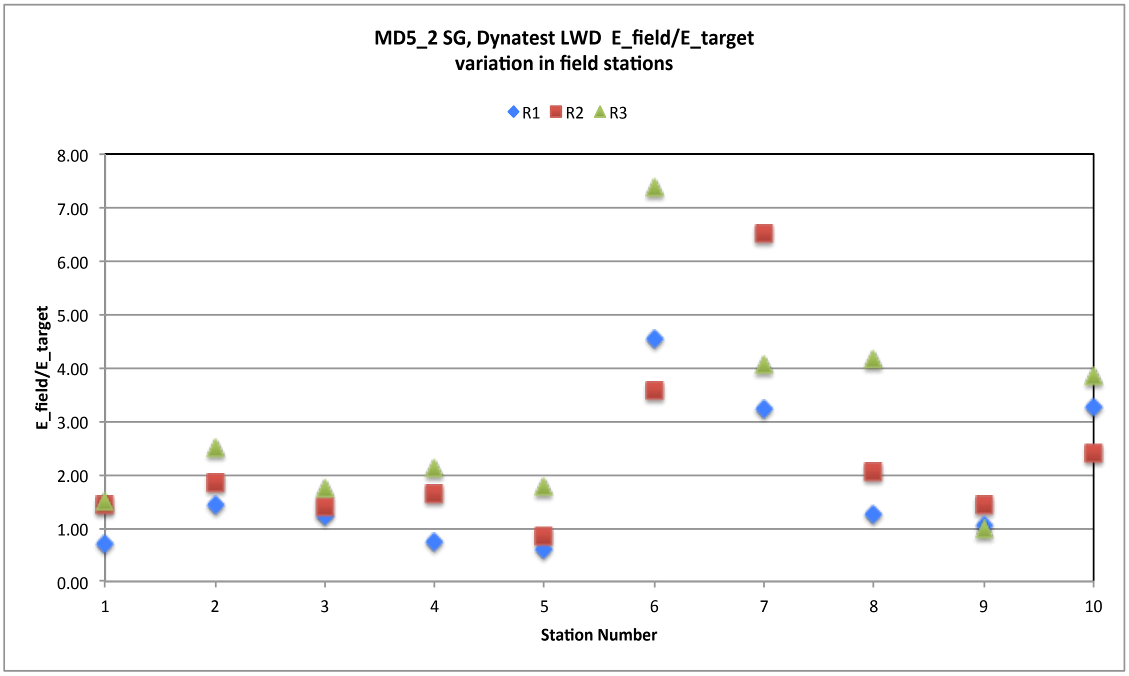


Figure 12- Measured field modulus to calculated target modulus ratio: Dynatest LWD.

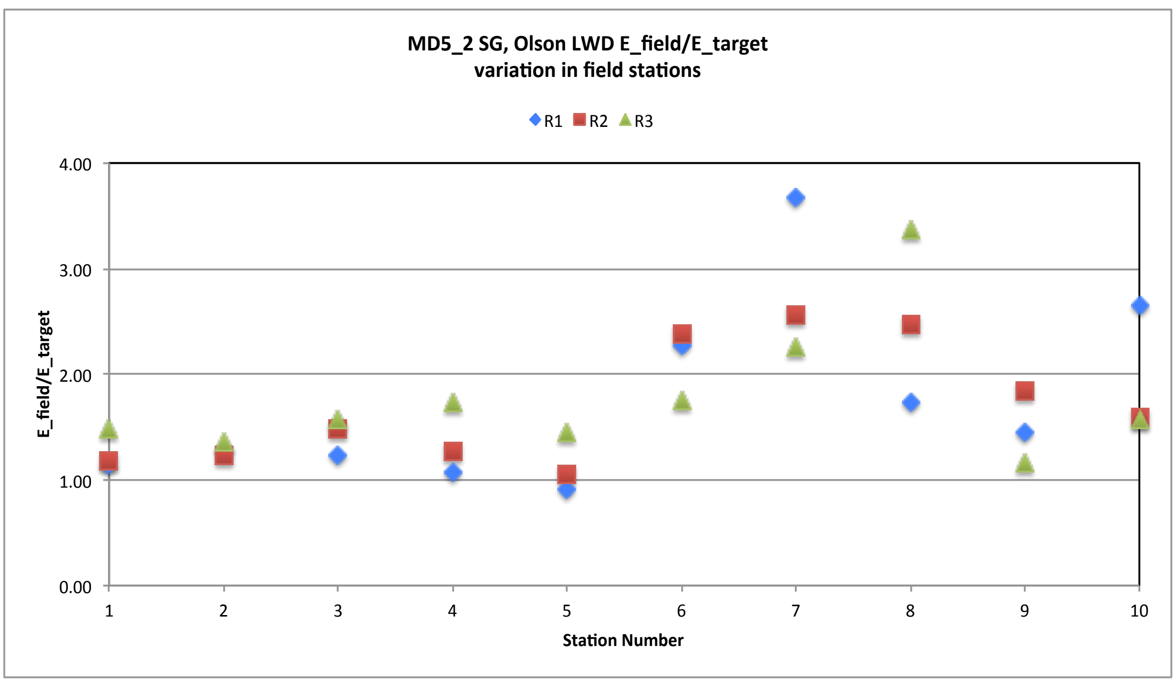


Figure 13- Measured field modulus to calculated target modulus ratio: Olson LWD.

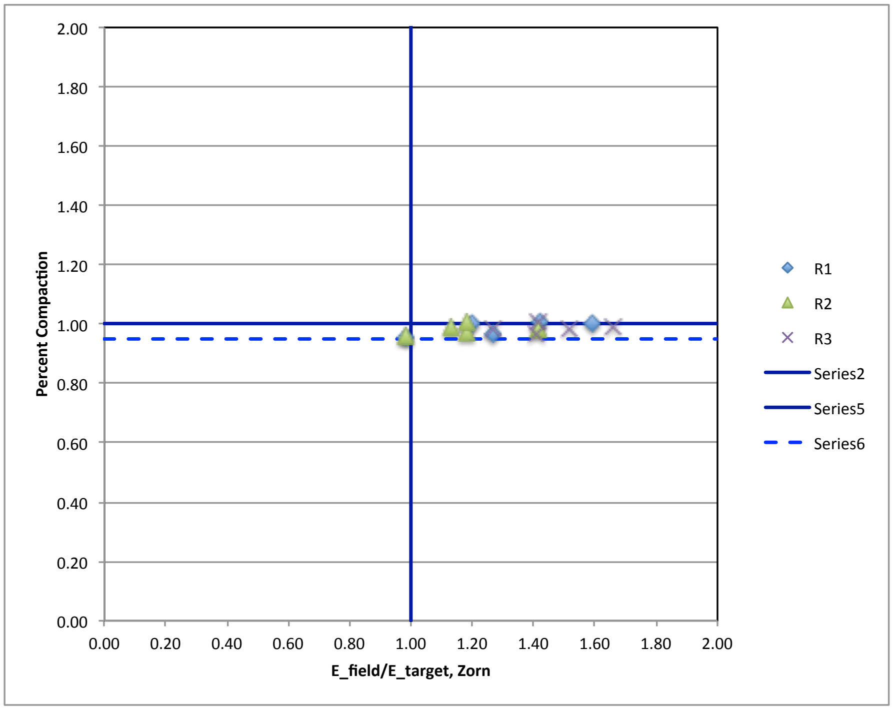


Figure 14- PC vs. Field to Target modulus ratio for Zorn LWD.

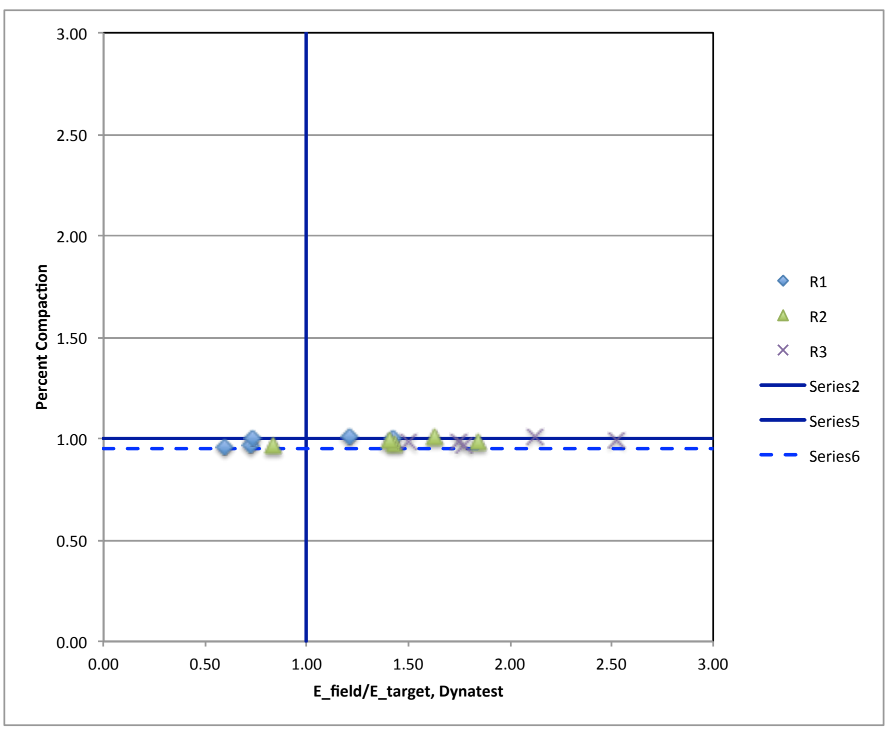


Figure 15- PC vs. Field to Target modulus ratio for Dynatest LWD.

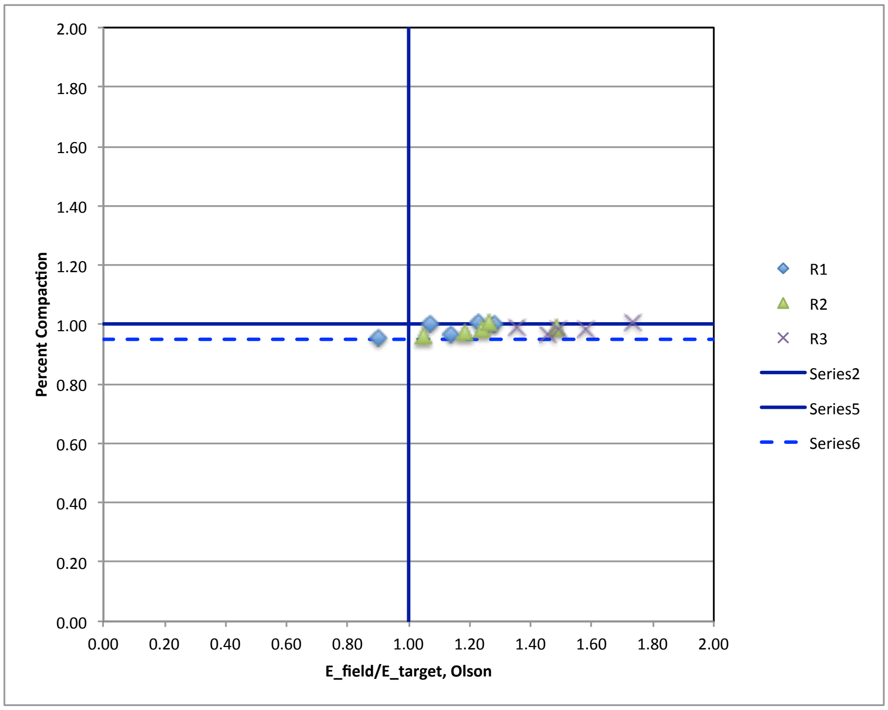


Figure 16- PC vs. Field to Target modulus ratio for Olson LWD.

Finally, a comparison of different LWDs performance is presented in the Figure 17, Figure 18, and Figure 19. As observed by others in previous studies, the different LWD devices give different values for field modulus. The field and target moduli values from the Dynatest LWD are consistently higher than from the Zorn. This is attributed to the Dynatest measuring deflection directly on the top of the soil through the center annulus; heaving of the soil into the annulus under load causes an underestimate of deflection and thus a higher modulus. The fact that the Zorn and Olson LWDs, both of which measure plate deflection rather than soil deflection, give similar moduli values is consistent with this explanation. However, since both the field and target moduli in these figures were determined using the same device in each case, the measurement differences largely cancel when looking at the ratio of E_field/E_target in Figure 19. However, the variability of this ratio is higher for the Dynatest LWD.

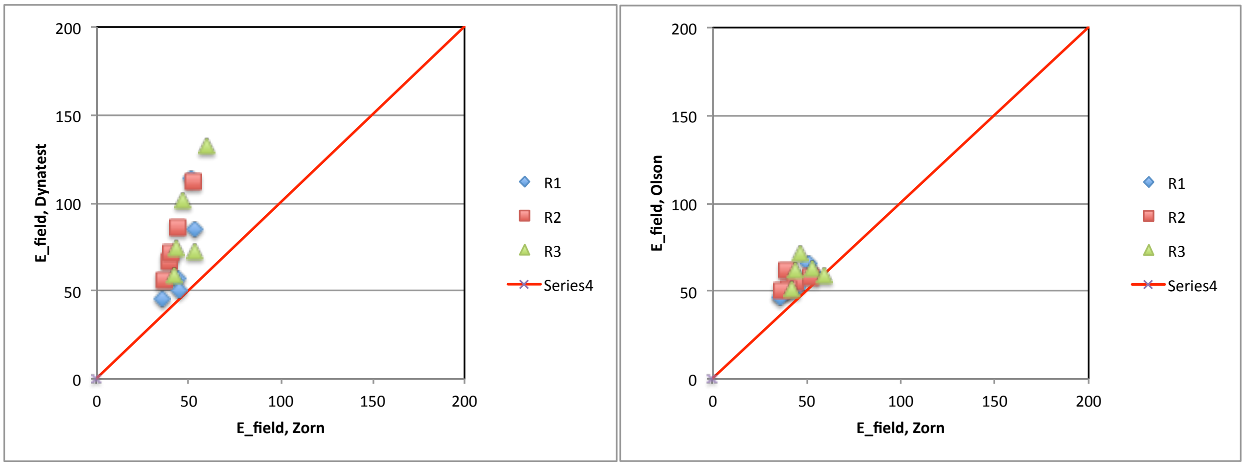


Figure 17- LWDs Field measured modulus correlation.

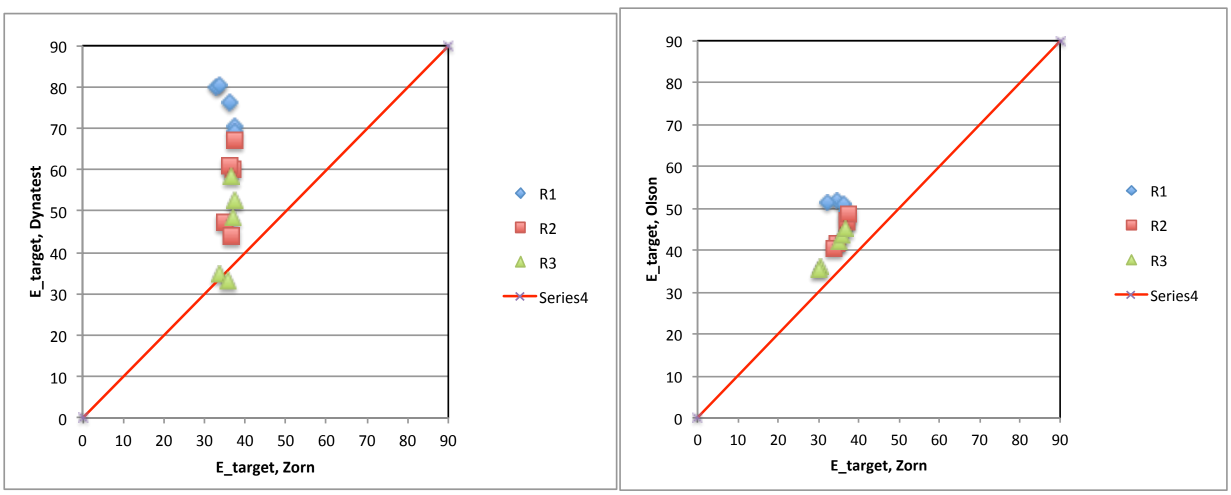


Figure 18- LWDs calculated Target modulus correlation.

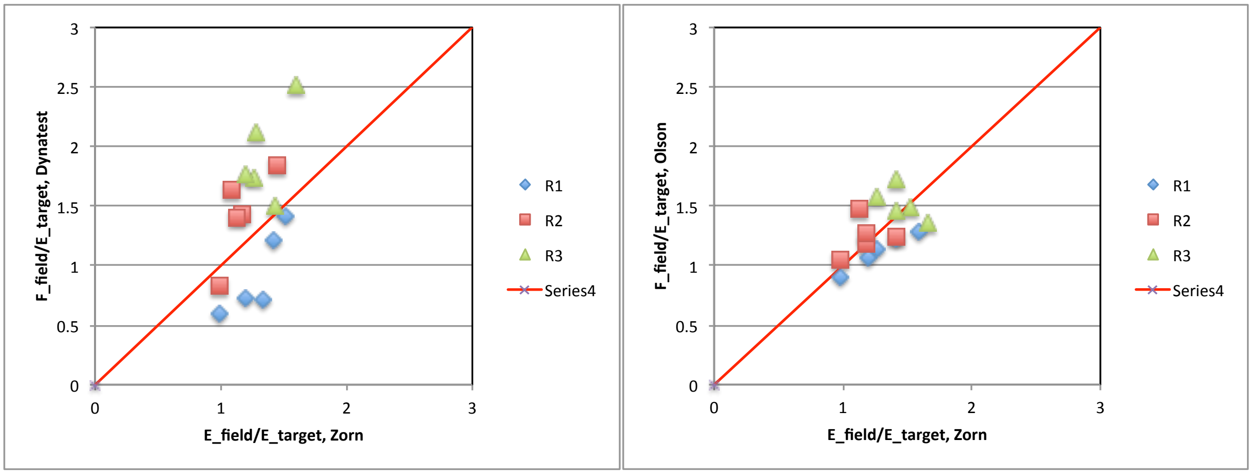


Figure 19- LWDs Field to Target modulus correlation.

Appendix B

LWD Devices Evaluation for Specification Refinement

We encountered several complications during the LWD testing on Proctor mold procedure. In order to improve the testing condition, several issues were considered and evaluated.

Effect of Proctor Mold size

Samples compacted according to AASHTO T-99 or T-180 can be prepared either in 4 inch or 6 inch diameter molds. Particular difficulties were encountered testing on the 4 inch diameter mold. First, the LWD plate size is the smallest so the applied pressure cannot be reduced to a P/Pa value near field conditions (P/Pa<=1) even at reduced drop heights (Figure 20 and Figure 22). The modulus must therefore be extrapolated to field conditions. For the 6 inch diameter mold and the larger LWD plate size, lower pressures can be achieved. The 1 to 2 inches drop height gives P/Pa values at or below field conditions so the modulus at field pressure can then be determined by interpolation rather than extrapolation.

Second, the Zorn 100mm LWD plate is very heavy. On 4 inch diameter molds, in particular, it leaves the surface unleveled with a considerable amount of permanent deformation. This is especially true for wet samples due to drainage of water from the mold (Figure 45). Also, if the subgrade includes coarser particles, it is difficult to provide a uniform distribution of coarse grains in each layer while compacting in the 4 inch mold. This also may contribute to the unevenness of the surface under the LWD plate.

Figure 21 presents results from tests on 4 inch molds to investigate the effect of the Plugin for the Dynatest LWD. The coefficient of variation for the last 3 drops was significant. Given this low quality data, it is impossible to draw any conclusions.

In order to avoid the complications described above, all subsequent LWD testing was performed on 6 inch diameter Proctor molds.

Dynatest with or without Plug

The Dynatest LWD was originally designed to measure deflection directly on top of soil through the central hole in the plate. There is an optional Plugin feature that closes this hole and forces the center geophone to measure plate deflection like the Zorn and Olson LWDs (Figure 42). In order to investigate this, a set of tests were performed on 6 inch diameter mold using the MD5_2

SG at 6%, 7%, and 8% target MC (around the OMC) and 6 drop heights in the Table 1. The results are presented in Figure 23 to Figure 41.

Generally, the Dynatest LWD deflections measured with the central hold plugged are less than when the hole is open and the deflections are measured on the top of the soil. As a consequence, the modulus with the central hole plugged is greater. The results were compared to Zorn and Olson LWD measurements. Since each LWD device has a different applied pressure, to make an fair comparison the data were plotted vs. P/Pa at each MC and interpolated for a P/Pa=1 to find modulus and deflection at constant normalized pressure for all devices. It was observed that although the deflections for all LWDs increase with increasing pressure, the modulus for Dynatest LWD decreased. This could be due to the buffer stiffness, which controls the rate of increase in applied load when increasing the drop heights.

While Olson and Zorn LWD modulus measurements were similar, using the Plugin option for the Dynatest reduced the Dynatest modulus from about 2 times to 1 time larger than the Zorn measured modulus (Figure 32, Figure 33, and Figure 34). Plate rigidity can also contribute to this discrepancy.

In conclusion, using the Dynatest plug considerably reduces the measured deflection and modulus to values closer to those measured by the Zorn and Olson LWDs. The plug also helps avoid the bias resulting from placing the center geophone directly on a coarse particle.

LWD Plate Jumping

Since the final soil surface is at the top edge or rim of the mold, the LWD plate would sometimes move onto the rim and produce an erroenous deflection. This happened most with with Zorn and Olson LWDs, which have heavier plates. In order to hold the plates in place and keep them from moving around after each drop, a collar was designed for placement on top of the mold (Figure 44). This significantly improved the test results and increased the speed of testing.

Scalping of Coarse Aggregate

According to AASHTO T-99 and T-180: “This test method applies to soil mixtures that have 40 percent or less retained on the 4.75 mm (No. 4) sieve when Method A or B is used and 30 percent or less retained on the 19.0-mm (3/4-in.) sieve when Method C or D is used. The material retained on these sieves shall be defined as oversized particles (coarse particles).”

So depending on the gradation, a large amount of coarse particles may be scalped off (Figure 43). This will change the soil’s structure. Although there are correction factors to adjust for the dry density and MC (AASHTO T-224), corrections for modulus/deflection are unknown. We recommended that the scalping sieve size be set so that it does not exclude a large portion of soil's aggregates. For example, if the scalping sieve for MD5_2 SF is set at 1 inch instead of ¾ inch, only 6% of the soil is scalped.

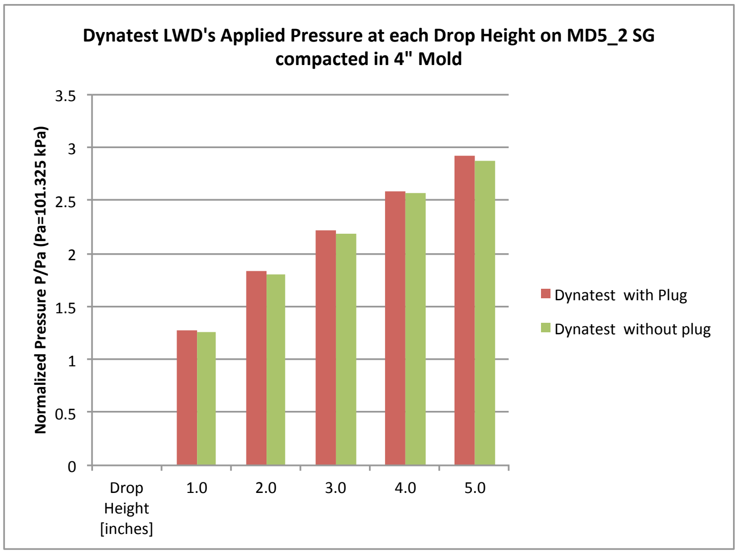


Figure 20- Applied pressure on 4 inch Proctor mold for Dynatest LWD with and without plug.

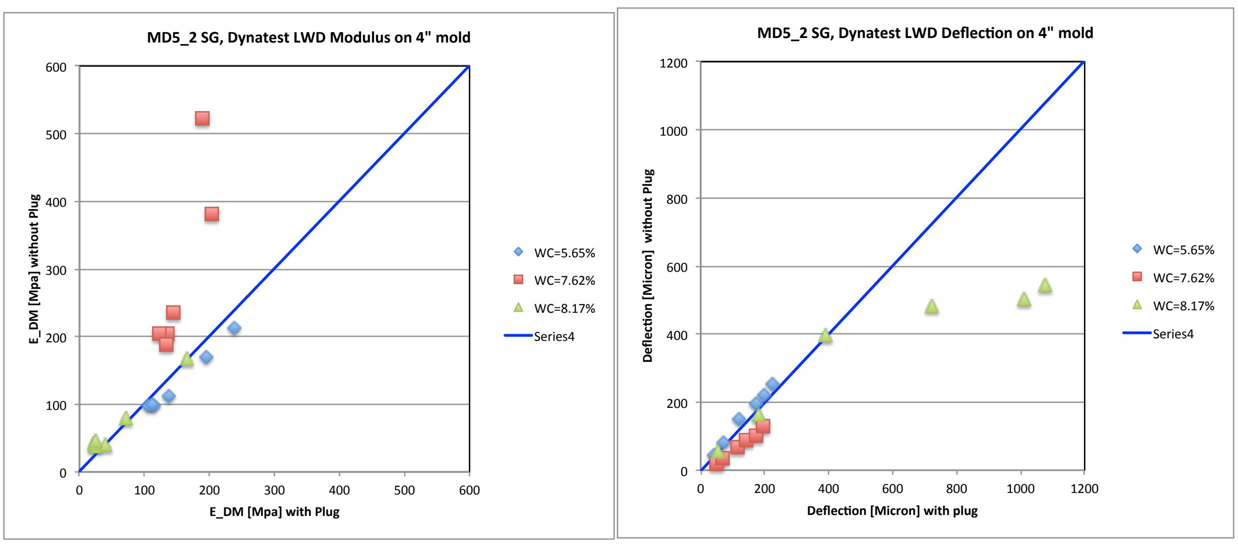


Figure 21. Measured modulus and deflection on 4 inch Proctor mold for Dynatest LWD with and without plug.

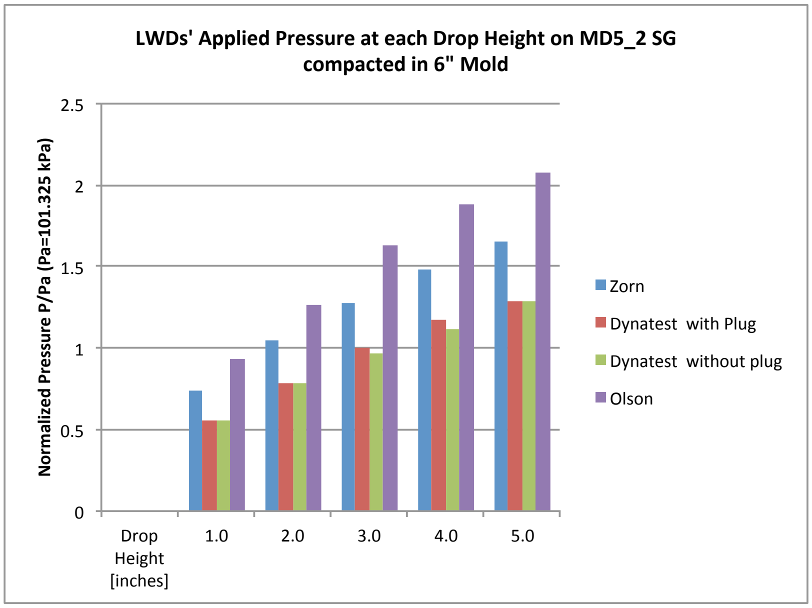


Figure 22- Applied pressure on 6 inch Proctor Mold for Zorn, Olson, and Dynatest LWDs (Dynatest with and without plug).

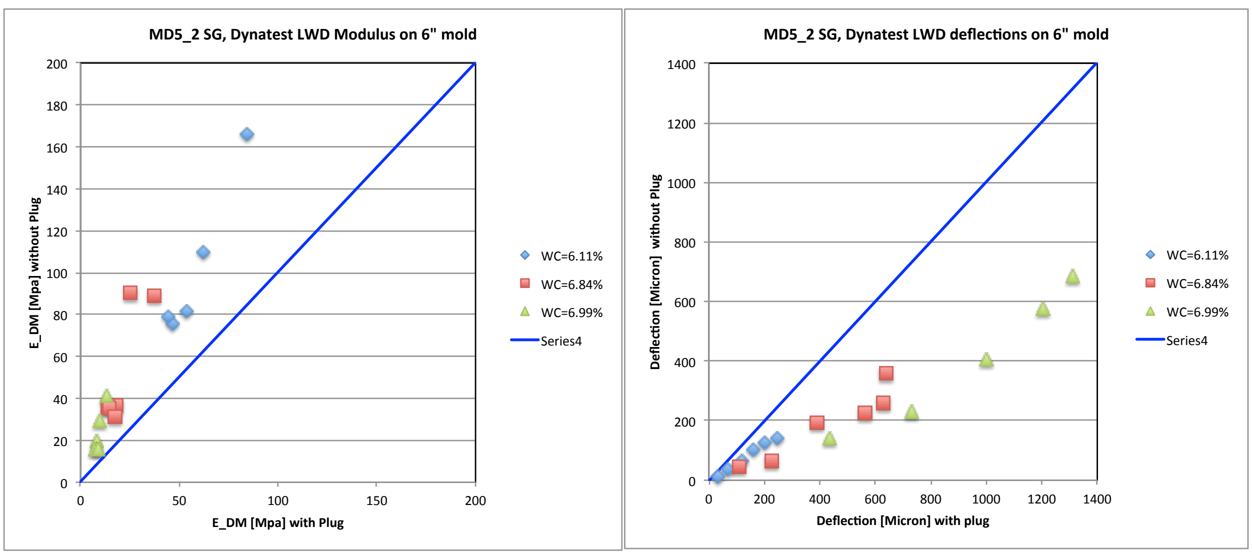


Figure 23. Measured modulus and deflection on 6 inch Proctor mold for Dynatest LWD with and without plug.

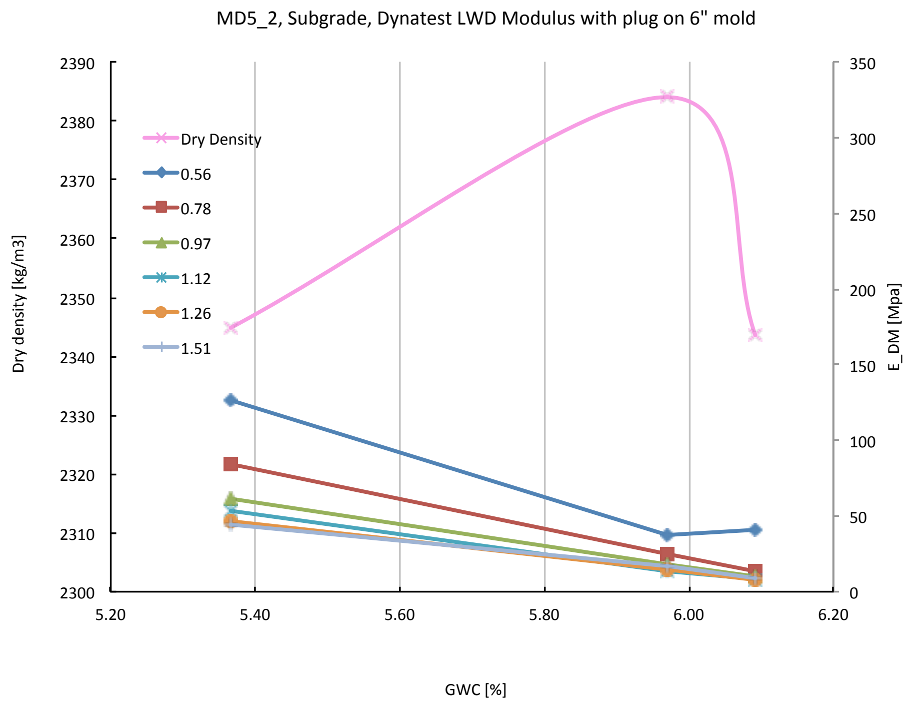


Figure 24

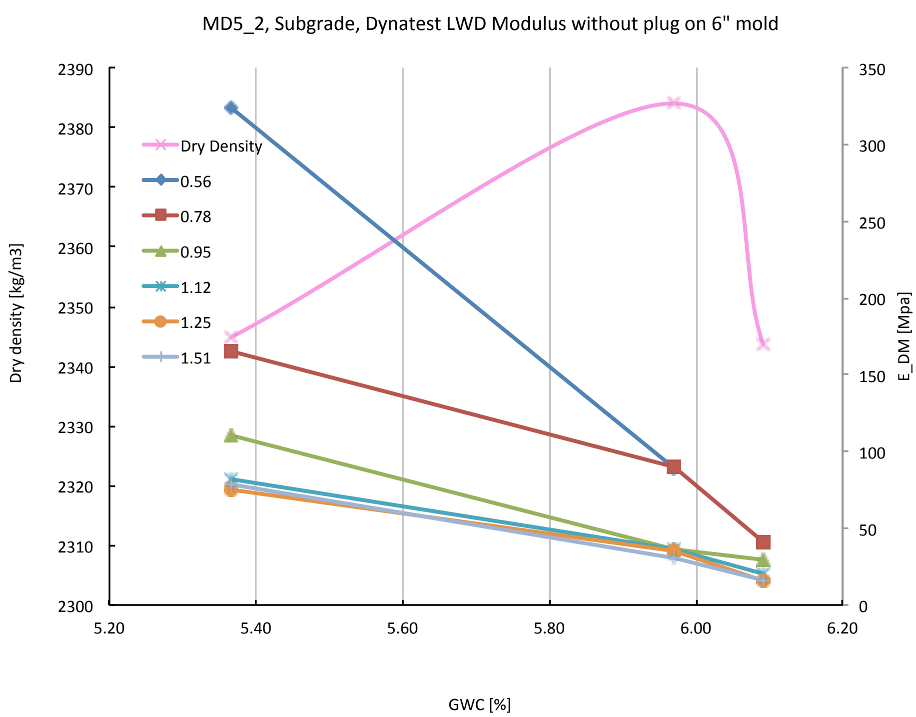


Figure 25

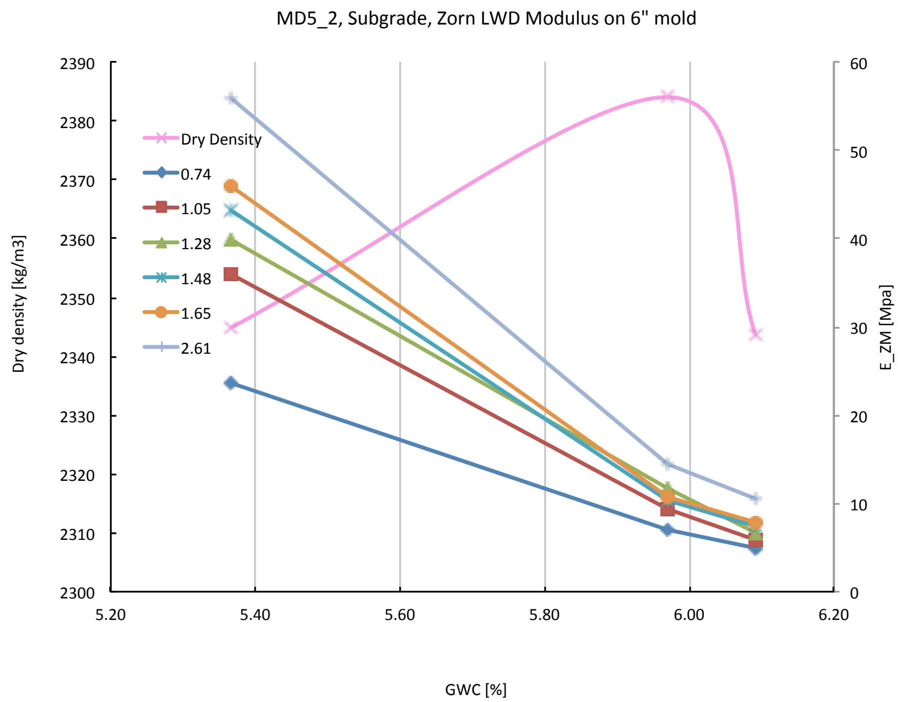


Figure 26

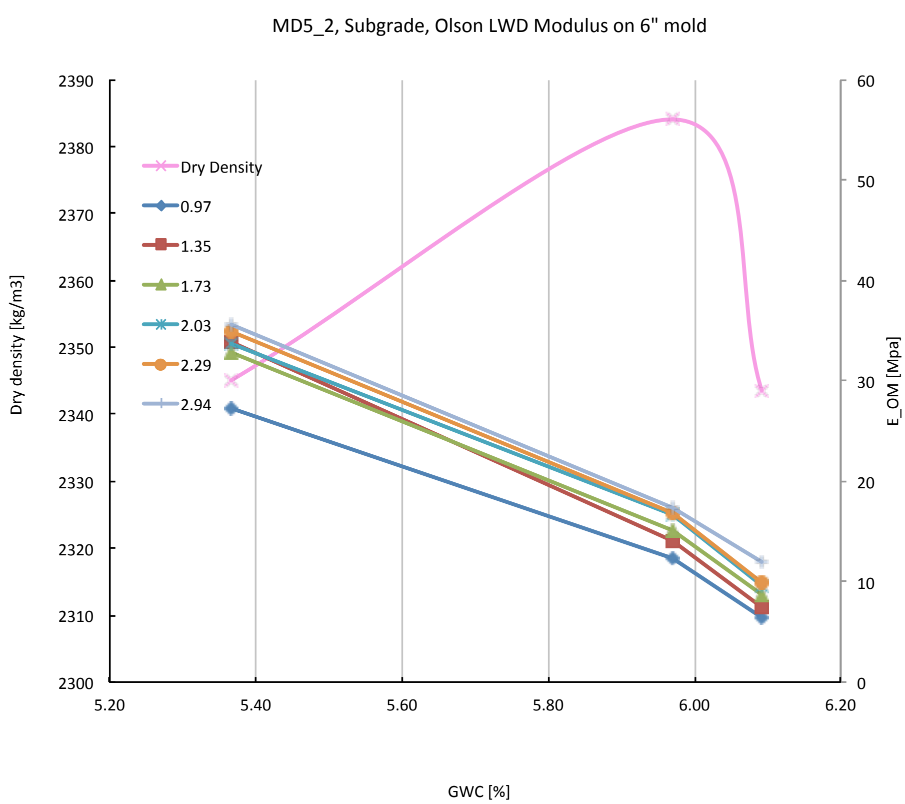
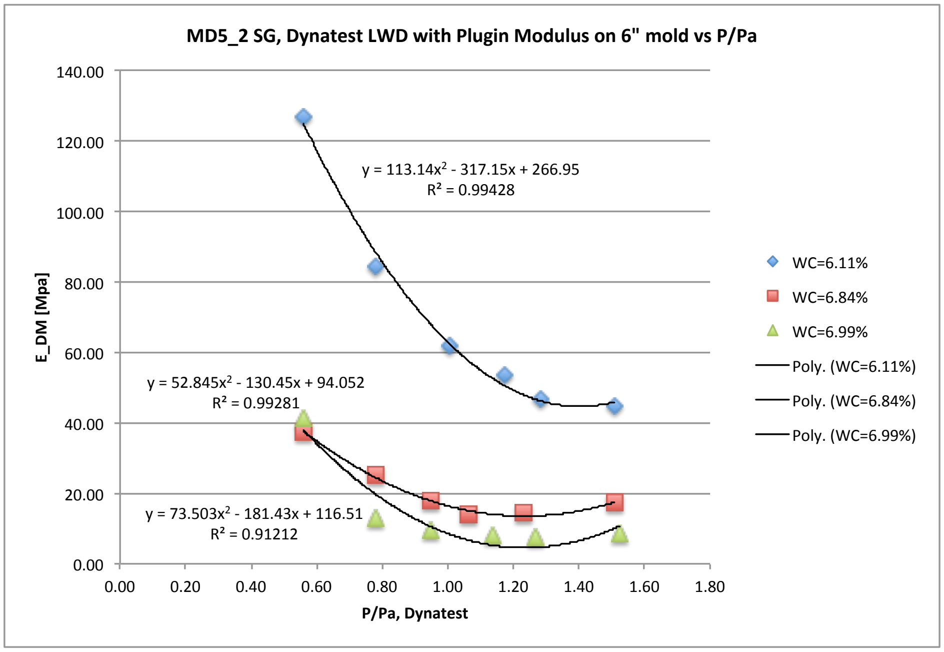


Figure 27



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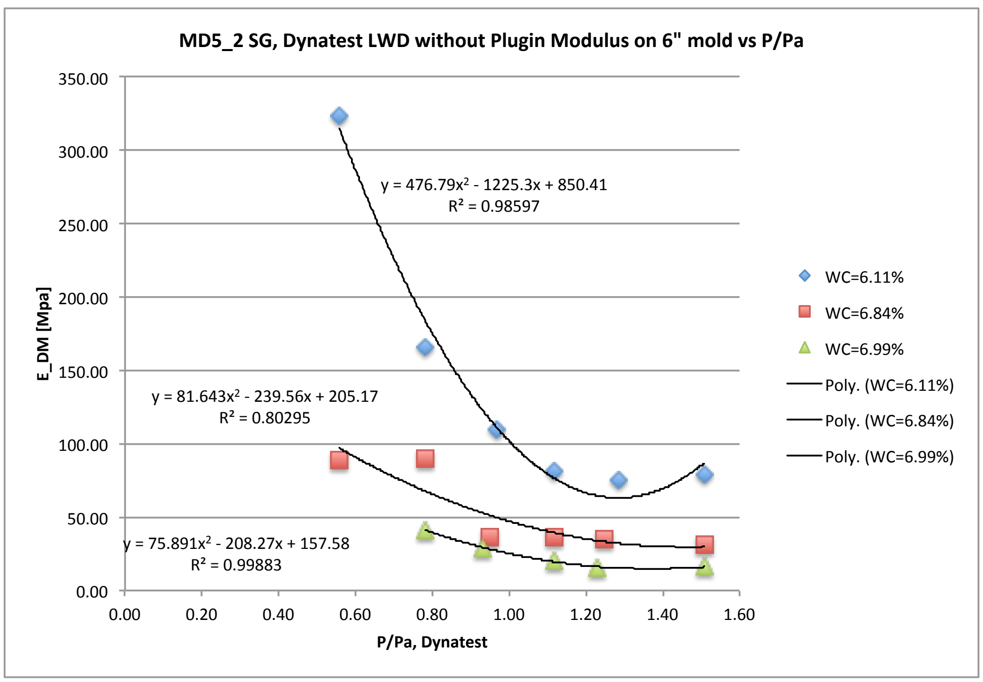

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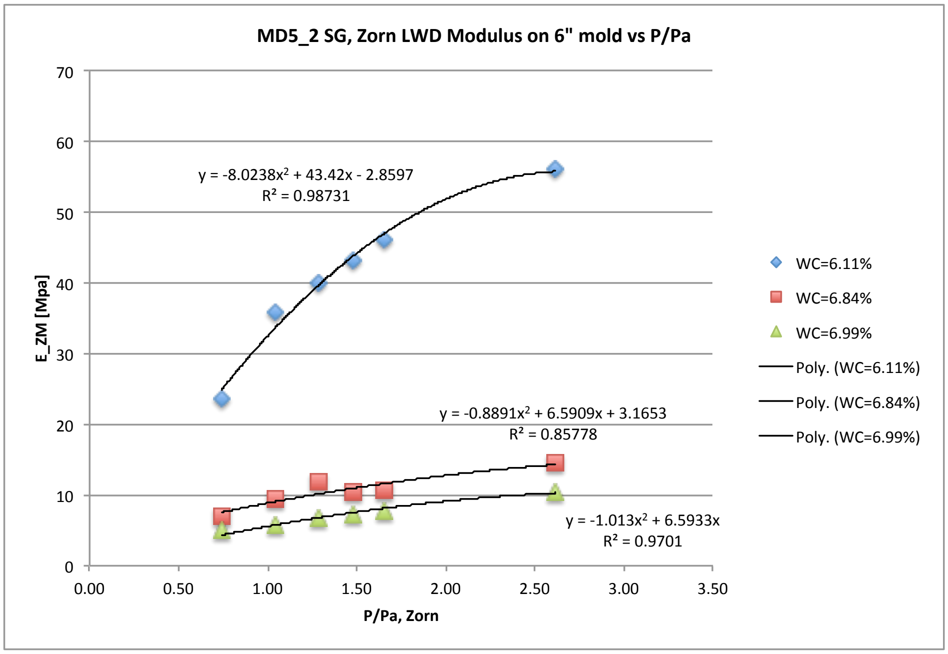

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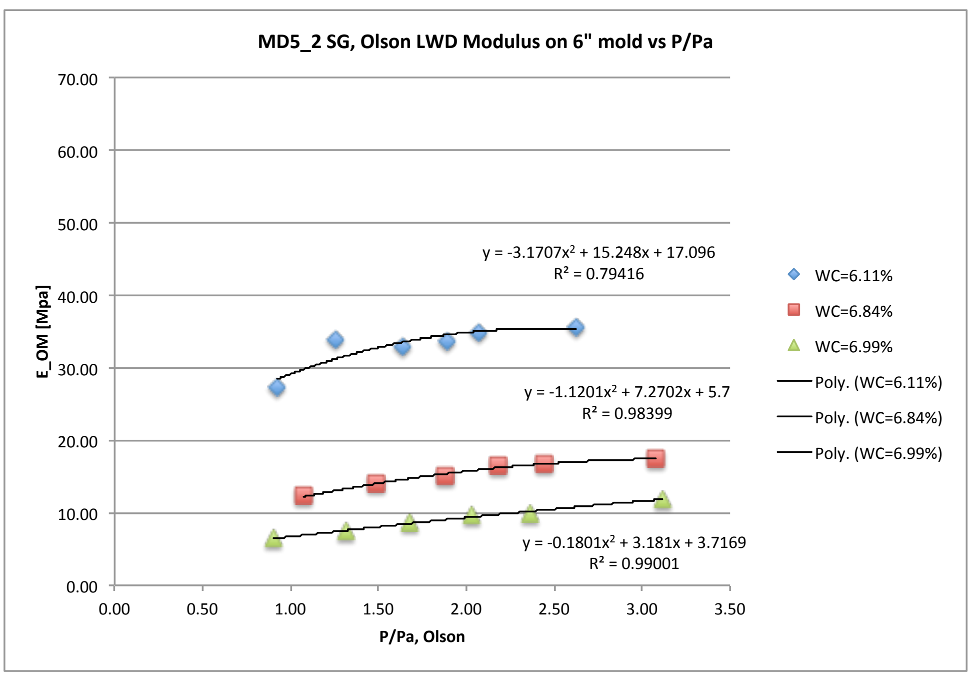

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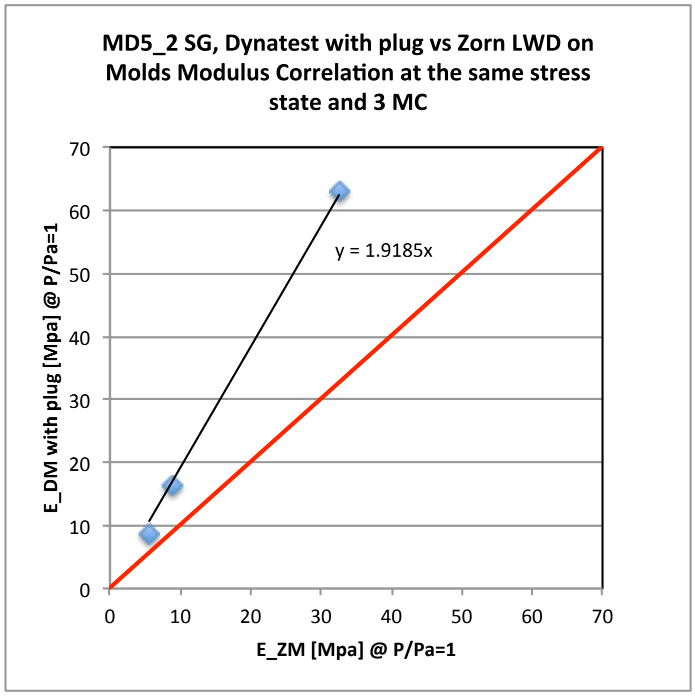


Figure 32

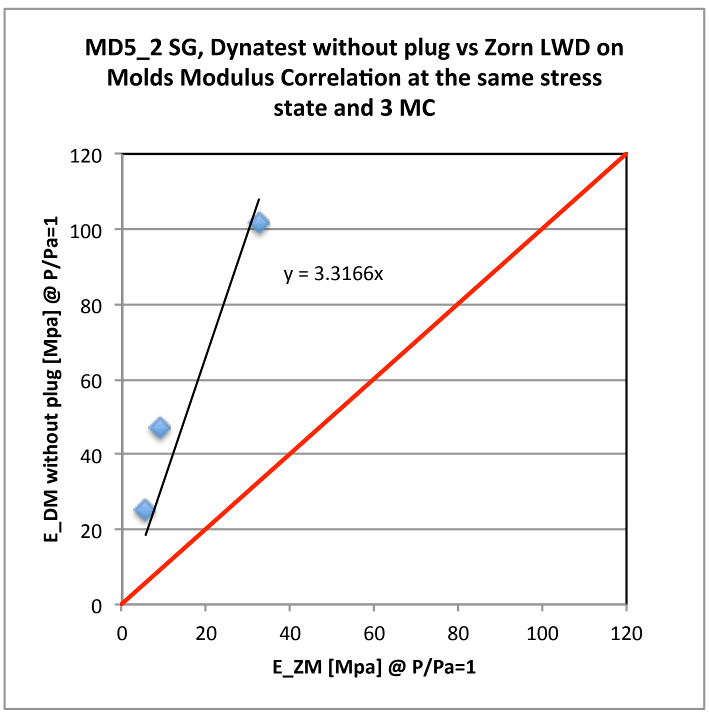
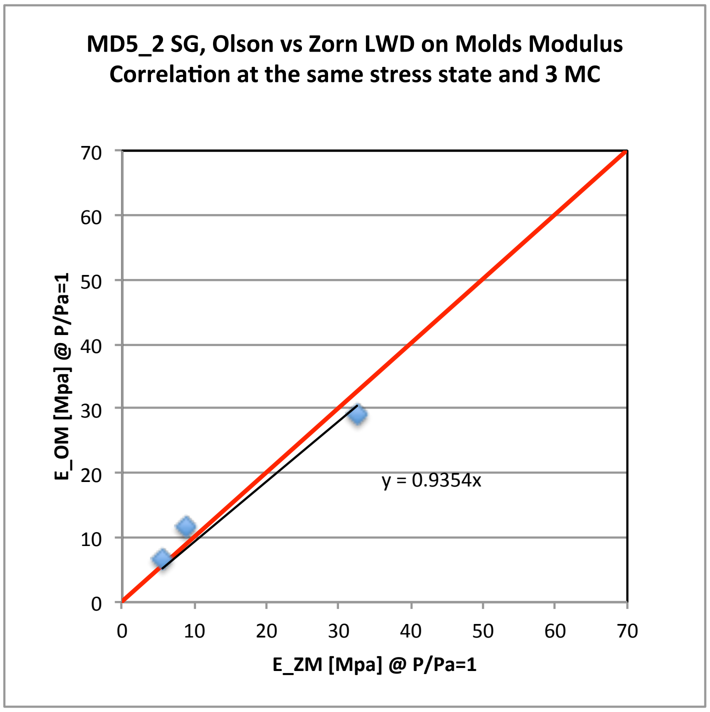


Figure 33



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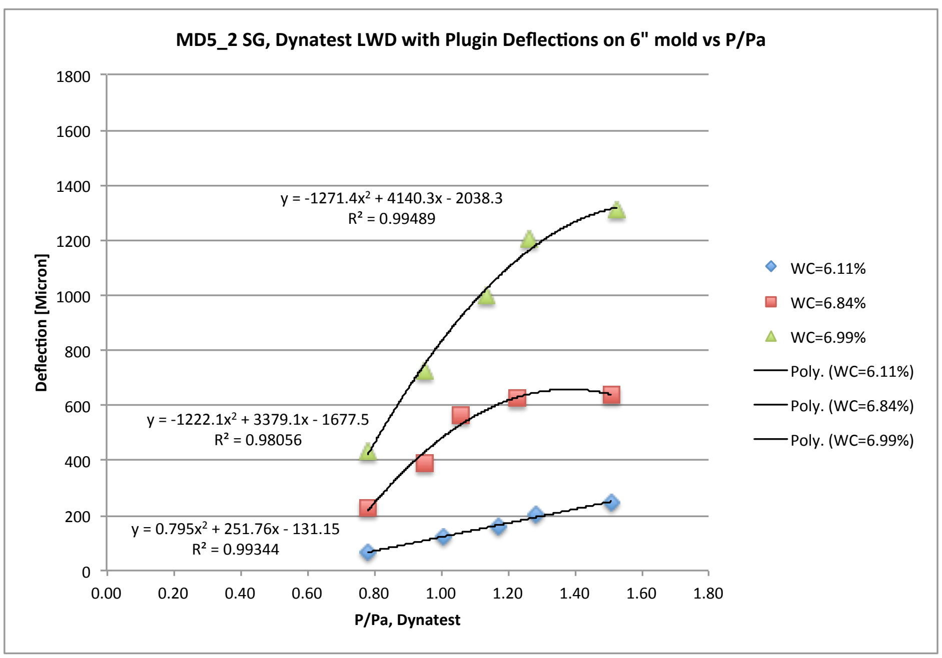

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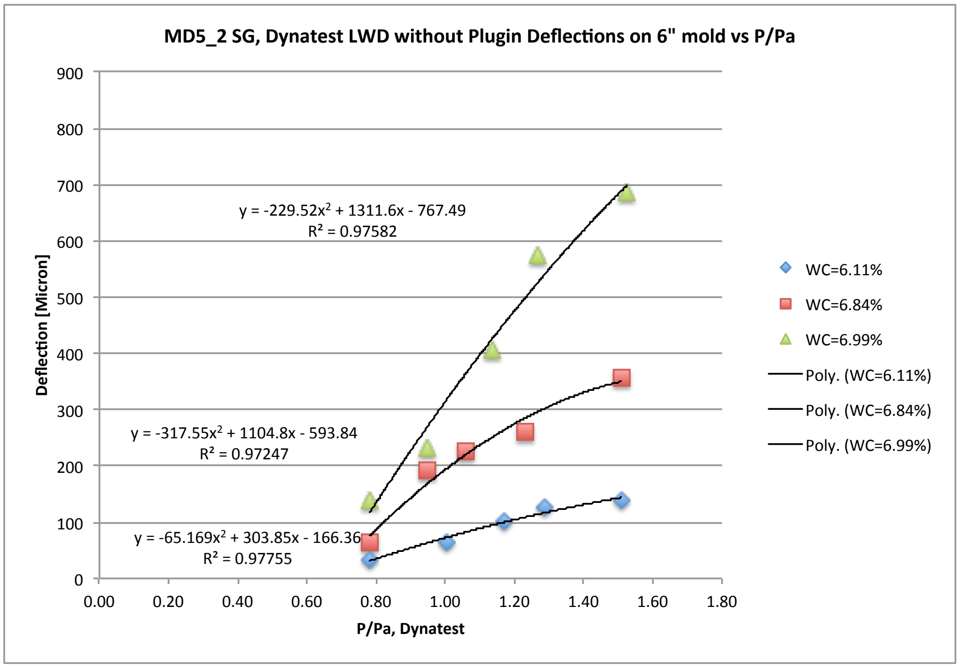

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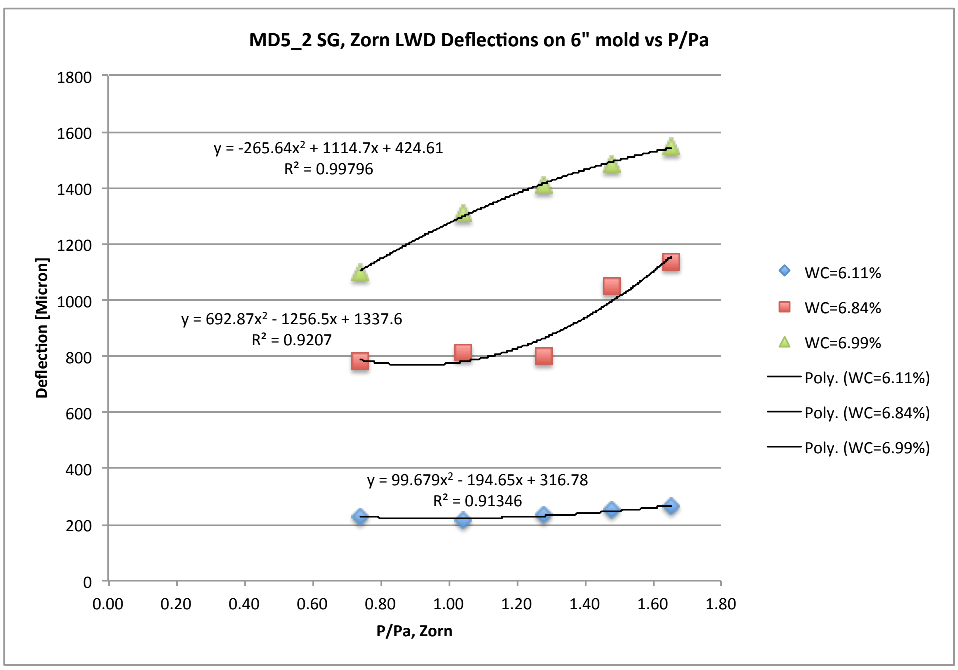

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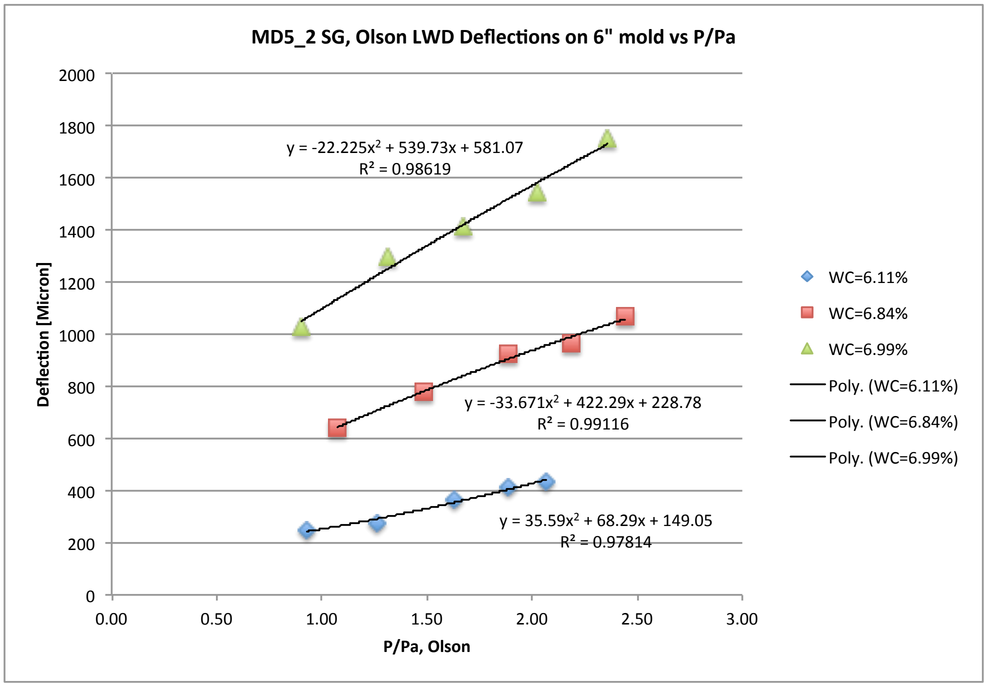

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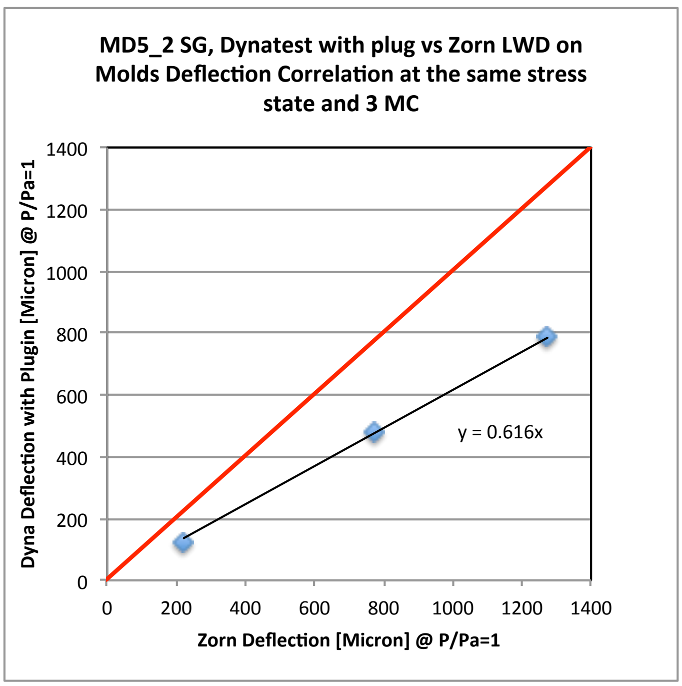

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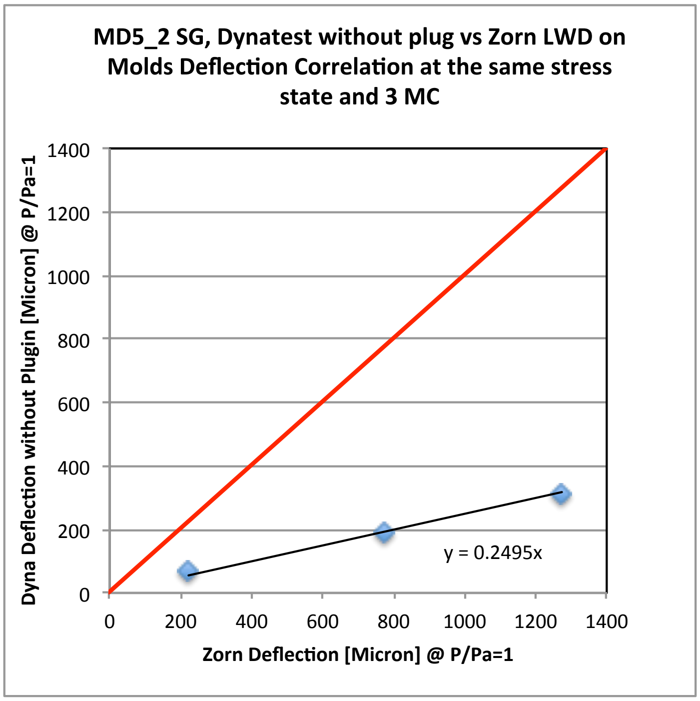

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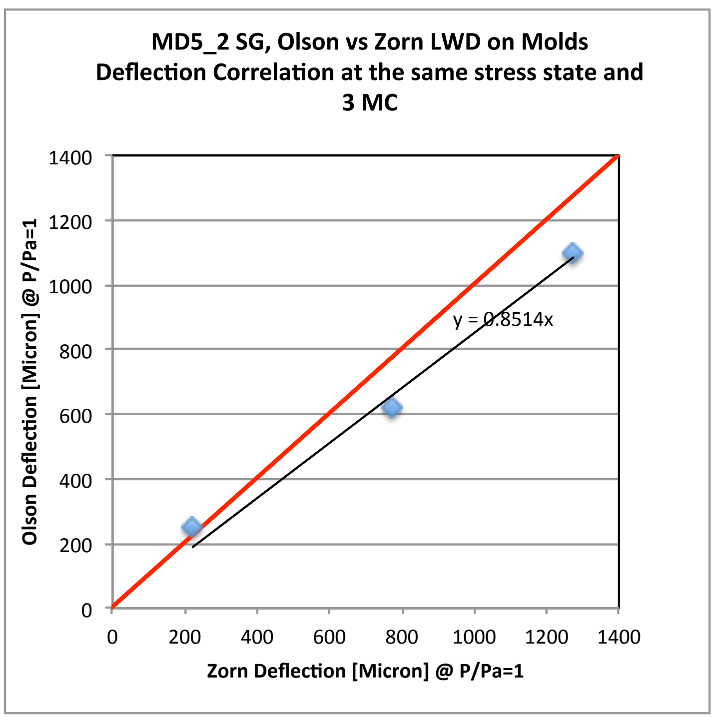

Figure 41

Figure 42- Dynatest Plugin to lock the center geophone for measurement of the plate deflection.

Figure 43- MD 5 Subgrade scalped coarse aggregate according to AASHTO T-99.

Figure 44- Collar designed for 4 inch and 6 inch molds.

Figure 45- Permanent deformation and unleveled surface in the 4 inch mold after testing with Zorn LWD.

Figure 46- Water drained from sample compacted on wet side of OMC during LWD on Proctor mold testing.