

Intelligent Compaction and Lightweight Deflectometer Technology Transfer Workshop

(IC & LWD Workshop)
Mn/DOT Baxter Headquarters Conference Room
November 14, 2007

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The following synthesizes the discussions that were documented during this workshop.

1.0 Lightweight Deflectometer Discussions

1.1 Positive Characteristics

1. Quick and easy.
2. Inspector remains on grade.
3. Made contractor more aware.
4. Better understanding of water content and process.
5. Uniformity improved.
6. Contractor gains understanding and buys into technology.
7. Clay Soils: LWD sound and rebound are also good indicators.
8. Testing typically takes 3 to 5 minutes.
9. Reliable measurements. One LWD test out of approximately 200 tests, where the LWD results did not match those of the DCP.
10. Improvement over the DCP. The LWD test is quicker and the Contractor better understands the results.

1.2 Troubles / Concerns

1. Water table can be drawn up and affect results.
2. Need to remove crust on clay prior to testing
3. Set up of soil (soil curing) / bridging.
4. Difficult portability in utility trenches.
5. Can be a 2 person job.
6. Need to level plate.
7. Not “light” weight.
8. Difficult to carry down into a trench on extension ladder.
9. What is “good enough”?
10. If sand is too wet and is sloped, the LWD will move.
11. IC compactor often agitates water to surface, therefore, come back 3 to 4 hours later to test with LWD.
12. IC steel drum roller does not achieve compaction as well as a rubber tired roller with sand.

13. Unable to obtain consistent LWD results, and consequently, unable to adequately use target value, with only 1 ft of sand above grade (e.g., clay). This trend is especially noted with fabric. Most sands are 2 ft or less (i.e., no large fills typically encountered).
14. Like the LWD as a tool, but difficult to implement current specification under these conditions.
15. Used furniture dollies with 6" diameter tires to carry LWD. The dolly worked good on clean sand, but was difficult to get into and out of the truck.

1.3 Quantitative Results

1. Able to find deeper soft layers.
2. Able to get better results near structures.
3. LWD more reliable than IC / Machine Drive Power (MDP).
4. 35 ft Trench: Clean sand, good moisture, passing readings with LWD (20 MPa); dug 6 inches and obtained better reading (40 MPa).
5. 3 to 4 ft sand: As lifts increase, the modulus values increased (e.g., 20 to 40 MPa as worked up to grade). Did not have scrapers, but belly dumps. The modulus values increased with free compaction. Even for cases where there was no traffic, the modulus would increase the next day.
6. Does any modulus number greater than the TV add much to compaction?
7. Why does the modulus increase over time? Pore pressure effects? Water drains out of system?
8. Class 6, Aggregate Base, Duluth: $E = 40$ MPa. $E = 60$ MPa after one day of traffic.
9. Did not notice significant effect from mild skew of testing surface.
10. Would illustration of the correlation with LWD and modified DCP help increase understanding of results?
11. Detroit Lakes ran LWD side by side with the sand cone and the devices correlated well.
12. Class 5 Target Value = 50 MPa.
13. Achieved similar modulus values after 3 ft and up.

1.4 Moisture Effects

1. Clays are moisture sensitive.
2. Variable soils change optimum moisture content.
3. Need to obtain relatively uniform moisture.
4. First control moisture then establish LWD target value.
5. Need adequate moisture content to get passing LWD readings.

6. Trench compaction / native soils: 3 passes of roller and LWD failed. Problem: Moisture
7. Increased moisture with granular materials yielded better modulus values.
8. Clay soils need to decrease moisture for passing modulus values.
9. Moisture tested with both the Speedy and Burn Method. Results within 1 percent.

1.5 QC Contractor Responsibility

1. Moisture testing and control was a continual battle.
2. Contractor personnel are interested and asking for LWD numbers.
3. Contractor is learning that scrapers should be run in different spots to achieve passing LWD numbers (i.e., compaction).

1.6 Testing Procedures

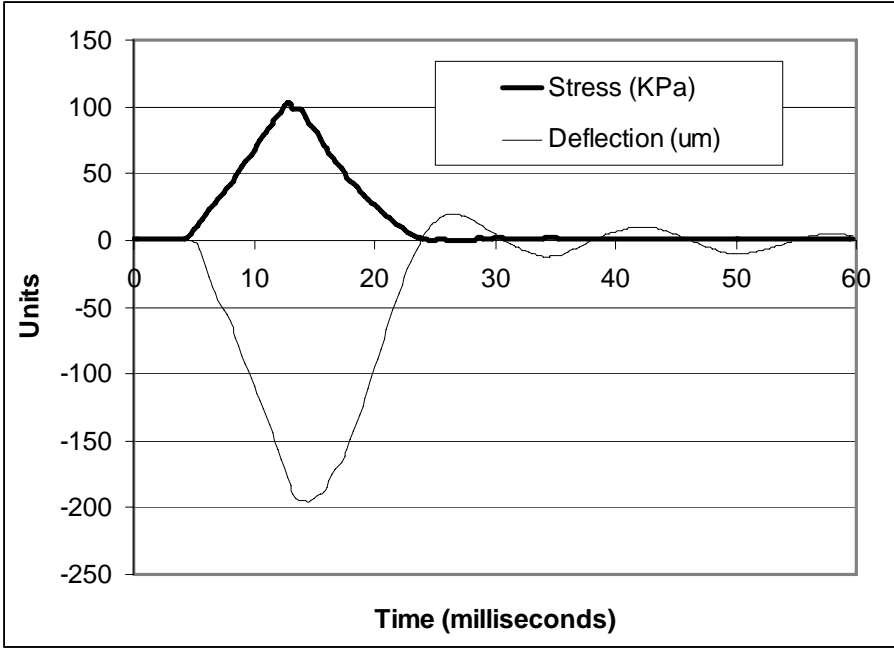
1. Removed 2 inches of “fluff”.
2. Removed 1 foot of material for testing in trenches.
3. Used LWD to determine rolling pattern in trenches, thereafter, the LWD was used for spot checks for practicality (due to difficulties of carrying equipment into trenches). Focused more on moisture content and lift thicknesses. Ensured that moisture content remained the same after determination of rolling pattern. Performed spot checks with LWD.
4. Seating Effects: Cut 0.2 ft. off of the top.
5. Trident: Performed approximately 150 tests. Problem: How soil is placed into cylinder. Began compacting soil and was obtained to obtain constant results. The trident works well in clean sand.
6. QA Procedure: First test for moisture, if moisture fails then Inspector does not waste time performing LWD testing. Full scrapers are often run over the site to help achieve density.
7. Determine base modulus value, since modulus values will increase over time.
8. Best time to test is at the time of compaction throughout the day. Cannot expect contractor to wait a day to blue top, etc.
9. Tested soft areas and every 300 to 400 ft.
10. Typically bridged 2 to 3 ft over clay.

1.5 Changes for Next Year

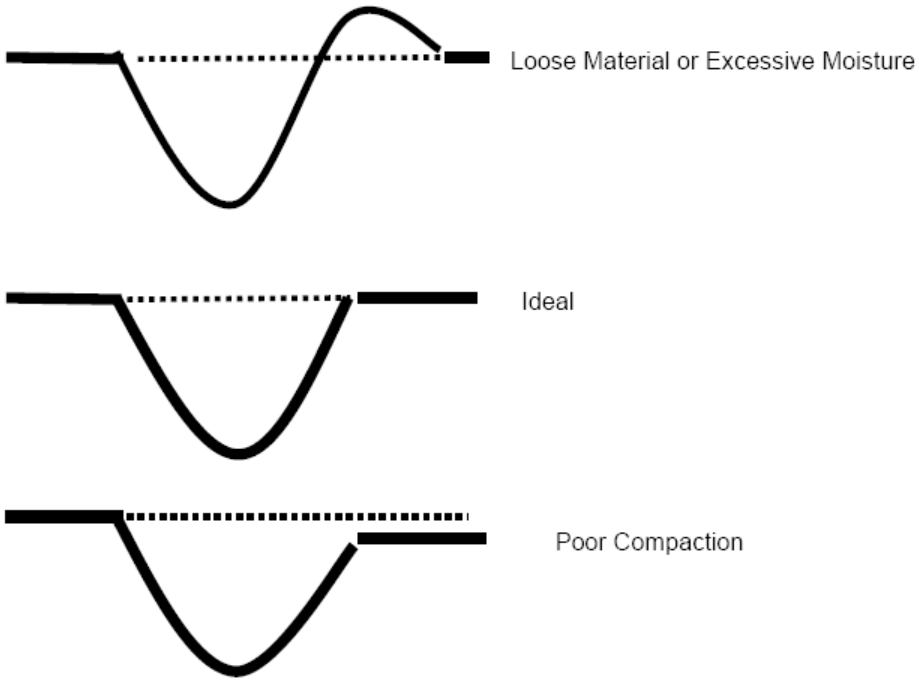
1. Procedures need to be flexible but balance with ability to enforce.
2. Need to standardize depth for granular to 4 inches.
3. Test on surface of aggregate base.
4. Timing of testing very important. Test close to equipment / timing close to compaction.
 - 4 to 5 % Passing #200:
 - i. $E = 30$ MPa (timing close to compaction)
 - ii. $E = 70$ MPa (2 weeks after construction traffic)
5. Control strips need to be eliminated.
6. Is not the DCP already working? Why do we need the LWD?
7. Materials where DCP not being used should be LWD focus.
8. Better if “over-built” then dug down for testing with some confinement.
9. 35’ Fill: Testing of top 3 to 4’ dig down? (Each lift test at 0”, 6” and 12”) to achieve modulus values.

1.6 Dr. Fleming’s Presentation “Experience with LWD for Routine In Situ Assessment of Foundation Stiffness”

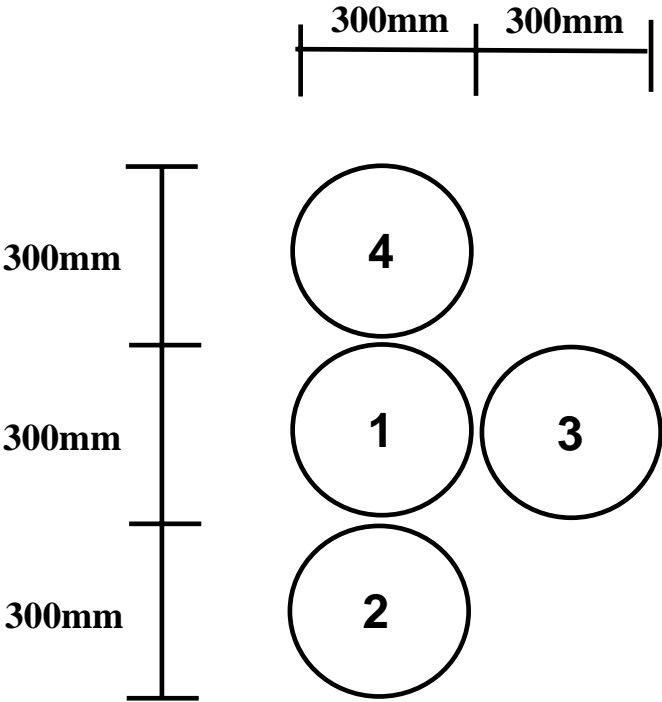
1. Use LWD values indirectly as compaction control, but directly with respect to performance.
2. Only test on surface in the UK.
3. Influence depth is approximately 1.5 times the LWD plate diameter.
4. Modulus values will always be site specific, in lieu of design-based target values.
5. Every 60 meters roll and average all modulus values (i.e., rolling average over 60 meters) and normalize to standard stress (176 KPa?). (200 kPa = 29 psi)
6. Perform LWD testing in demonstration areas.
7. Rolling average of 6 helps smooth out section data. Look at average and minimum values and compare to target value.
8. Measure force and deflection.
9. Data quality: Smooth time history traces of load and deflection indicate clean signal (good impact).



Typical Signal Responses from Prima 100 Software



- 10. Coefficient of variation: Subgrade (Clay) = 25 to 60%, granular capping = 10 to 40% and Granular subbase = 5 to 15%.
- 11. Coefficient of variation between adjacent points with Zorn: Capping (55-200 MPa)= 20 to 38%, Capping (25-150 MPa) = 15 to 21%, Sub-formation = 11 to 29%.



- 12. Calibration: yearly or every 2 years. “In house” device checks include floors, rubber mats, etc. for repeatability.
- 13. Warm up buffers / springs with 10 drops (temperatures greater than 4 to 5°C).
- 14. Seating: Unbound = 3 drops, Bound = 1 drop
- 15. Test at full drop height and 60 and 40 % of full drop height (stress sensitivity effects).
- 16. Good Seating: plate does not rock, limited variation between drops (< 10%), sinusoidal load pulse (smooth). Considered, but do not recommend, adding sand/rubber mat to improve contact since this is very subjective.
- 17. Test Quality: Smooth response (sinusoidal, free of peaks), acceptable rebound in deflection trace.

1.7 Dr. White's Presentation "Mn/DOT Intelligent Compaction Implementation Seminar #4: Lessons Learned from IC and LWD Testing"

1. Roller-integrated compaction measurements are empirically related to in-situ spot test measurements (γ_d , w%, DPC, E_{LWD} , etc.) and influenced by roller size, vibration amplitude/frequency, velocity, soil type and stratigraphy of underlying soil.
2. Uniformity is the key to good pavement performance.
3. Lesson #1: Uniformity of the pavement foundation is important, but difficult to achieve with current practices.
4. Lesson #2: IC data and LWD/DCP measurements show similar spatial variation.
5. Lesson #3: One cannot run enough spot tests to create highly reliable spatial maps. IC is the best method to achieve these maps.
6. Lesson #4: The LWD modulus is affected by plate diameter, drop height (contact stress), plate rigidity, stress distribution and device configuration.
7. Differences in deflection measurements are the major contributor to differences in LWD modulus values.
8. The assumption of a constant force (as assumed for the Zorn) is not a big contributor for differences in LWD modulus values on compacted surfaces.
9. Lesson #5: Preliminary results show that the resilient modulus is correlated to LWD elastic modulus. More data is needed for further verification.
10. Lesson #6: Moisture content (and density) is an important parameter to consider when developing correlations between IC and in-situ measurement values, and relating to ME design parameters.
11. LWD modulus values are sensitive to:
 - a. Localized disturbance of testing surface.
 - b. Confinement (for sandy soils)
 - c. Geophone / Plate seating
 - d. Levelness of the testing surface
 - e. Several other factors not included here.
12. The LWD recommended testing protocol is as follows:
 - a. The test surface should be level and smooth. Levelness can be checked with a bubble level. The LWD plate should not translate laterally with successive drops.
 - b. Perform 3 seating drops before collecting data for consistent measurements. If noticeable deflection or bearing capacity failure occurs, the material needs further compaction or is too wet. For stiff materials, one or two seating drops may be sufficient and can be

determined by collecting data and demonstrating that successive seating drops do not increase the modulus by more than 5 percent.

- c. Following the seating drops, perform three drops of the falling weight for a given drop height recording data for each drop. If ELWD values successively increase with each drop exceeding 10% of the previous measurement, additional compaction is likely needed.
 - d. Standard plate diameter and drop heights of 200 mm and 50 cm, respectively, are adequate for the range of materials tested in MN.
 - e. Preliminary findings indicate a significant increase in LWD modulus values (~150 percent increase) at a depth of 150 mm.
 - f. For non-granular (cohesive) materials compacted with padfoot rollers experience has shown that more repeatable LWD results are obtained by removing the cohesive soil to a depth equal to the depth of the padfoot penetration.
 - g. For stiff granular base materials with sufficient particle size and particle interlock, tests performed at the surface after smooth drum compaction are generally recommended because of the difficulties with excavating a level surface.
 - h. In general, the test elevation for (1) granular materials, especially fine sands, should be performed at a depth of 150 mm below the compaction surface, (2) Nongranular materials compacted with padfoot rollers should be at the bottom of the padfoot penetration, and (3) granular base/stabilization layer materials should be at the surface of the compaction layer.
 - i. Where a pit is required for LWD testing, its diameter should be = 2 times the plate diameter (i.e. 400 mm for 200 mm plate).
13. The COV for compacted granular materials ranges from 10 to 25 percent and for compacted non-granular materials from 30 to 40 percent.
14. One question that has come up is how many tests are adequate to develop a target value from calibration/control strips. This question can be addressed using a simple statistical model.

$$L = y \pm t_{\alpha} \sqrt{\frac{s^2}{n}}$$

Where L is the confidence limit of the average (target) value, t_{α} is the Student's t with $(n - 1)$ degrees of freedom, α is the probability level and s^2 is the variance.

15. From analyzing the variability of LWD measurement values, increasing the number of test measurements improves the statistical confidence in the limits.
16. Lesson #7 (Test Rolling vs. IC and In-Situ Measurement Values): The LWD modulus correlated to rut depth based on preliminary measurements. More measurements are to be collected in 2008.

2.0 Intelligent Compaction Discussions

2.1 Positive Characteristics

1. Better uniformity.
2. Less man power required.
3. The IC software was user friendly.
4. Assists with determination of poor and good spots.
5. Helps ensure that weak spots are not covered up.
6. When the IC indicated poor material, it was confirmed with the LWD.
7. Found spreadsheet of estimated moisture contents does a good job (only off by a couple of points). It is plenty adequate for select granular.
8. IC is good when building up everything at the same time.

2.2 Troubles / Concerns

1. Delay with software and general training. Slow AccuGrade Software delivery.
2. No substitute for Inspector on job.
3. Passing CCV values might not be indicative of indeed passing (false positives).
4. Difficulties resulting from water table. Several feet of embankment was needed to bridge subcut areas.
5. Dynapac did not meet specifications. GPS accuracy limited to 10 ft.
6. Roller operator never kept in communication loop.
7. Difficult for Contractor to meet Mn/DOT specifications (e.g., limited functionality of IC software making it difficult to provide maps).
8. The Roller Operator could determine when the material needed additional water, however, no one would be receptive to their comments.

9. Incompatibility between QA and QC location units. QA locations were generated in Station, Offset and depth from grading grade, while the IC locations were x, y, and z coordinates. Difficult to correlate locations.
10. IC production maps were printed for every 300 to 400 ft, resulting in approximately 150 pages of mapping. Additionally, paper maps had no reference points.
11. Is the IC cost effective on small projects? It significantly slowed progress on the 5 mile job.
12. Need additional equipment beyond the IC.
13. A large number of false readings due to bridging/crusting.
14. Concern over IC readings. MDP on concrete slab is supposed to be 150, in Bigelow the IC readings were 150 on clay.
15. Specification too loose for clay.
16. There were cases where the IC passed, but the LWD indicated failure. Contractor is wondering why Mn/DOT is requiring the use of the IC roller?
17. Drum bridging on wheel track was often used as an excuse for poor areas.
18. Cannot shut off proofing measurements at end when roller turns around. These values are included in the calculations on the CD700.
19. Scrapers often pumping water back up.
20. Not interested in machine drive power.
21. IC roller lighter than production rollers.
22. How will IC roller work on plastic soils?
23. Contractor does not see direct benefit.
24. Rolling is not a pay item.
25. Roller Operator does not always communicate to Inspector when weak spots are present due to pressures from Foreman.
26. Inspectors cannot always look at CD700 screen on roller.
27. Bridging. Used LWD below crust and still failed.
28. Proof layer being 90 of 90% of TV is not acceptable.
29. Roller Operator wanted to know why the soil was not passing.
30. Roller Operator did not want to use IC roller.
31. 3 inch ridge will fail the soil.

2.3 Quantitative Results

1. CCV = 30 to 40, TV-LWD = 40 MPa
2. Bigelow: Some negotiations in acceptable IC-TV (e.g., Minimum MDP value of 142 was acceptable, 138-141 was questionable, in future would move minimum up to 144). Found MDP of 143 would fail with the LWD and at other times a MDP of 138 would pass with the LWD. Not black and white.

2.4 Testing Procedures

1. Did not use AccuGrade software 100 percent to verify machine due to large amounts of data and limited resources.
2. Areas had to be bridged prior to some proofing runs to obtain adequate numbers.
3. Not concerned with compaction measurement values exceeding 120%.

2.5 Changes for Next Year

1. Never switch 100% to IC as QA. Keep LWD as QA.
2. Requirement that Roller Operator is adequately trained (certification required?).
3. Radio required for Roller Operator. The Roller Operator could not communicate with Foreman or water truck.
4. Need other IC manufacturers included in future projects, in lieu of 100% Caterpillar.
5. Rolling in the subcut is not very useful, but only as a starting point. Water was often running in from sides. Grading better application.
6. Should not use IC with machine drive power as acceptance on Clay materials.
7. IC not cost effective on smaller projects due to increased staging needs / running back and forth with roller on job (e.g., Urban block by block is not effective with IC – peace meal work).
8. IC is effective on larger projects.
9. Increase number of rollers on job, but still use IC roller for proofing runs.
10. Why don't we have minimum moisture requirements on select granular when we have it on aggregate base? Depends on #200, but can be controlled by moisture content (5 to 6.5% would be preference). 4% on job requires additional time to achieve passing.
11. Do not write specifications by % of TV. Need better system.
12. Mapping on bottom of subcut is meaningless, since soft areas did not show up in the next layer.
13. Need both CCV and MDP values.
14. Real-time IC data transfer needed.
15. Use optimum moisture content estimate spreadsheet.

3.0 Agenda

The following outlines the agenda followed during this workshop.

9:30 a.m. Introductions
9:45 a.m. Split Up into Two Groups and Discuss what was learn from the Project Personnel about LWD

Discussion Topics

1. What worked in the field
2. What quirks were observed in the field
3. How did the moisture influence the LWD readings
4. What limits (machine, ...etc.) were observed in the field
5. What changes need to be done for next year
6. Other info

10:15 a.m. Review Groups Discussions about LWD
10:45 a.m. Keynote Speaker - Dr. Fleming
11:30 a.m. Lunch – On your own
12:30 p.m. Split Up into Two Groups and Discuss what was learn from the Project Personnel about IC

Discussion Topics

1. What worked in the field
2. What quirks were observed in the field
3. How did the moisture influence the IC readings
4. What limits (machine, ...etc.) were observed in the field
5. What changes need to be done for next year
6. Other info

1:00 p.m. Review Groups Discussions about IC
1:30 p.m. Keynote Speaker - Dr. White
2:15 p.m. Break
2:30 p.m. Wrap Up
3:00 p.m. Adjourn

4.0 Attendance List

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Attendance List (continued)

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