INTELLIGENT
COMPACTION

Never Guess Again

Jimmy Si, Ph.D., P.E. Tempe, AZ, Nov. 13, 2013
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We’ve known it for a long time …..

“The importance of compaction in highway construction has long been recognized. Recent laboratory and field investigation have repeatedly emphasized the value of thorough consolidation in both the base and surfacing courses.”

Reference --"Public Roads, May 1939, authors J.T. Pauls and J.F. Goode"
Significance of Quality Compaction

Reflection of underlying non-uniformity to overlying layers
• Intelligent Compaction (IC) is an innovation continuous compaction control process that

  – **measures** material stiffness during the compaction process,

  – **analyzes** the information being collected,

  – **makes** an adjustment of vibratory roller parameters, and

  – **executes** the change to optimize the compaction effort.
What Is Intelligent Compaction (IC)?

- Vibratory rollers with a feedback control measurement system
  - Measures material stiffness
  - Control system automatically changes parameters (amplitude and frequency) based on the measured material stiffness

- GPS-based documentation system
  - Continuous monitoring material’s stiffness and corresponding roller locations
  - Real-time displaying color-coded mapping of stiffness
What Is Intelligent Compaction (IC)?
How Does It Work?

Amplitude & Frequency Control

Soft Soil, poorly compacted; acting as a spring

Hard Soil, well compacted; acting as an anvil

High Amplitude, Low Frequency, Penetrate Deeper

Low Amplitude, High Frequency, Compact Surface

Courtesy of Ammann America
How Does It Work?

GPS-based Compaction Measurement

GPS – Satellite

Roller Stiffness

140 MN/m

70 MN/m

10 MN/m

none

GPS reference point

Courtesy of Ammann America
Compaction Control Process

How Does It Work?

GPS – Satellite

Forward

Backward

Pass 1

Pass 2

Pass 3

Pass 4

Courtesy of Ammann America
Why Do We Need It?

- **Current Practice**
  - Lab Compaction
    - Tex-113-E and Tex-114-E
  - Field Compaction
    - Ordinary Compaction (Proof Rolling)
    - Density Control
      - Sand cone replacement test
      - Nuclear gauge test (density and moisture)
Why Do We Need It?

- Problems
  - Compactive Energy
  - Moisture Content
  - Material Type
  - Compact Lift Thickness
  - Underlying Conditions

- Is density measurement the best way to assess the quality of compaction?
  - Density is not used in pavement design
  - Density is not correlated well with modulus/stiffness
Why Do We Need It?

- How do we know the target density is achieved?
  - Contractor
  - Proof rolling
  - Density by NDG

  - Density measurements are spot check and layer specific, and not representing the entire section (no info about uniformity of compaction)
  - Density is only measured after compaction is complete (no feedback in real time)
Intelligent compaction can greatly improve the quality and uniformity of compaction which are critical for long-lasting performance of pavements.

- When and how much of compaction is achieved, avoiding under or over compaction.
- Where compaction is achieved or not achieved.

Faster, Better, Smarter, and Safer
Never Guess Again
National and TxDOT Research

- **NCHRP 21-09**
  “Examining the Benefits and Adoptability of Intelligent Soil Compaction”
  - Colorado School of Mines, Michael Mooney and David White, et al
  - Final report (NCHRP report 676, “Intelligent Soil Compaction Systems”) has been released,

- **FHWA TPF-5(128)**
  “Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base and Asphalt Pavement Material”
  - The Transtec Group, Inc., George Chang, David White, and Larry Michael, et al
  - Final report (FHWA-IF-12-002) has been released,
Transportation Pooled Fund
TPF-5(128)
National and TxDOT Research

- FHWA EDC2 Initiative
  Report on the EDC2 Summits
  [Report link](http://www.fhwa.dot.gov/everydaycounts/pdfs/edc2_2013.pdf)

  - Accelerating Project Delivery
  - Reducing Construction Time
  - Innovative Contracting
  - Safety
  - Environment
  - Mobility

  More info: [More info link](http://www.fhwa.dot.gov/everydaycounts/edctwo/2012/ic.cfm)
FHWA TIDP 130(096)
“Intelligent Compaction Roller Retrofit Kit Validation”
– University of Texas at El Paso, Soheil Nazarian and George Chang, et al

TxDOT 0-6740
“Improvement of Construction Quality Control by Using Intelligent Compaction Technology for Base and Soil”
– University of Texas at El Paso, Soheil Nazarian, et al
TXDOT IC PROJECTS
5 Districts, 14 IC projects
Fort Worth (8)
- FM156; DFW Connector;
- US287; FM1938; FM731;
- SH267; IH35W; and IH30

Paris (2)
- SH24
- US75

Atlanta (1)
- FM450

Houston (1)
- SH35

Amarillo (1)
- LP335

El Paso (1)
- FM1281
- FM 156, Fort Worth, TX, 2008
- FHWA/TPF IC Study
- Cohesive SG, Lime Stabilized SG, and Aggregate Base (Flex Base)

**padfoot drum IC roller**  **smooth drum IC roller**

Dynapac Single Smooth drum IC roller
Case/Ammann Single-drum padfoot IC roller

Ks shows compaction progress and a soft area

Screen shots of kSIPD maps for different passes on TB 1

TxDOT FM156 Project
k_{SIPD} measurement from different passes on TB1 lanes 1 and 5 (nominal \( a = 0.8 \) mm, \( f = 35 \) Hz, and \( v = 3.5 \) km/h)
Spatial comparison of $k_{SIPD}$ and $k_{SISD}$ maps (TB 1 – subgrade clay material)
**Underground Structures**

Point 1
- $E_{LWD-Z2} = 61.1$ MPa
- $E_{V1} = 42.1$ MPa
- $E_{V2} = 121.1$ MPa
- $E_{FWD-D3} = 57$ MPa
- $E_{D-SPA} = 88$ MPa

Point 12
- $E_{LWD-Z2} = 47.5$ MPa
- $E_{V1} = 42.1$ MPa
- $E_{V2} = 121.1$ MPa
- $E_{FWD-D3} = 57$ MPa
- $E_{D-SPA} = 44$ MPa

Point 13
- $E_{LWD-Z2} = 58.4$ MPa
- $E_{V1} = 96.9$ MPa
- $E_{V2} = 381.1$ MPa
- $E_{FWD-D3} = 145$ MPa
- $E_{D-SPA} = 88$ MPa

Box Culvert
- $w = 29.5\%$
- $\gamma_d = 13.8$ kN/m$^3$
- $E_{LWD-Z2} = 11.6$ MPa

Case/Ammann Single-drum padfoot IC roller
Identify Different Materials

CMV Map $a = 1.2$ mm, $f = 30$ Hz, $v = 3.5$ km/h

CMV Map $a = 1.9$ mm, $f = 30$ Hz, $v = 3.5$ km/h

Lane 2

Flex Base

Lime Stabilized SG

Flex Base

Dynapac
Single Smooth drum IC roller
CMV maps on TB 7 with different operation settings

Map 1 Manual Setting 2  $a = 0.9 \text{ mm}$
Map 2 Manual Setting 3  $a = 1.1 \text{ mm}$
Map 3 Auto Setting 5  $a_{(max)} = 2.4 \text{ mm}$
IC vs. Conventional Tests

Box culvert at 8 in. depth

$k_{s30}$ Map $a = 0.8$ mm, $f = 30$ Hz, and $v = 3.2$ km/h
8-mile highway that connects SH114 and SH121 and adjacent roadways located north of the DFW International Airport

$1.1 billion design-build project (CDA)

Groundbreaking Feb. 17, 2010. Expected to complete in 2014

Approximately half the construction time needed as opposed to traditional contracts
Materials
- SG, lime treated SG, and flex base

IC Implementation (MDP)
- Production Rolling
- Proof Mapping
  - QC Testing (verified by LWD)
  - QA Testing (verified by PLT, not yet implemented)
DFW Secondary Site Base Compaction Report

Compaction Report
Data Model: DFW SITE
Display: CCV
Site: DFW-SECONDARY SITE
Date: Wednesday, August 08, 2012
Compaction Analysis
- > 147.0 (94%)
- 142.0 (6%)
- 127.8 (1%)
- 112.0 (1%)
- 0.0 (0%)
Target CCV
Target CCV: 142.0
Target CCV Range: 142.0 - 142.0
CCV Summary
- Overcompacted: 99%
- Complied: 0%
- Undercompacted: 1%
- Total Area Covered: 341.897 sq FT
- Duration: 9h 55m 10s
Filter Settings
- Filter: <Not Specified>
- Machine: JCB 801-11-TES
- Time Start: 5/30/2012 - 05:54:23 pm
- Time End: 5/31/2012 - 07:48:47 pm

Compaction Analysis
- > 147.0 (94%)
- 142.0 (6%)
- 127.8 (1%)
- 112.0 (1%)
- 0.0 (0%)
Target CCV
Target CCV: 142.0
Target CCV Range: 142.0 - 142.0
Compaction Target Value (CTV) = 42

<table>
<thead>
<tr>
<th>% Target</th>
<th>CCV</th>
<th>IC Data</th>
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<tr>
<td>&gt;130%</td>
<td>55</td>
<td>26%</td>
</tr>
<tr>
<td>90-130%</td>
<td>38 - 55</td>
<td>68%</td>
</tr>
<tr>
<td>80-90%</td>
<td>34 - 38</td>
<td>4%</td>
</tr>
<tr>
<td>70-80%</td>
<td>29 - 34</td>
<td>1%</td>
</tr>
<tr>
<td>&lt;70%</td>
<td>&lt; 20</td>
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Current TxDOT QA Criteria:
>90% of IC Data should be equal to or greater than the 85% of CTV
Benefits

- Cover 100% of the rolling area, resulting in better control of density and its uniformity
- Replace conventional proof rolling
- Identify soft spots in real time
- Improve pavement performance
- Improve site safety

Challenges

- Extensive educational training
- Data Management and Standardization
- Moisture content measurements and variations
- Poor correlation between density and modulus/stiffness
What Is Next?

- Increase awareness and encourage the use of IC technology in all districts
- Conduct training workshops and/or Webinars in all 25 TxDOT districts for IC technology implementation including IC retrofit kits
What Is Next?

- Conduct demonstration or pilot projects in TxDOT subgrade/base construction using IC technology
- Revise TxDOT current OUT (one-time-use) project-based IC special specification
- Develop a state-wide use IC specification
  - Short Term: density acceptance based on IC mapping
  - Long Term: eliminate NDG density acceptance
QUESTIONS?

Jimmy Si
512-506-5901
Jimmy.Si@txdot.gov