Intelligent Compaction Discussion

1. Why is compaction important?
2. How do you measure compaction?
   a) Historic
   b) Roller/Compactor Integrated
      i. Soil Compaction Measurement (CMV, MDP)
      ii. Temperature Measurement (asphalt)
   c) Intelligent Compaction (define: measurement, positioning and data)
   d) GNSS positioning & mapping of the jobsite
3. IC as a “process control” for Asphalt Compaction
4. Data management
5. Asphalt example: Benefits of IC (rolling pattern)
6. Summary
7. Questions?
Why is compaction important?
Why is compaction important?
Historic Compaction Measurement

Nuclear Gauge

(DCP) Penetrometer

(LWD) Deflectometer

Plate Load
Question:

With the traditional or historic compaction sample testing, what percentage of the surface is generally assessed?

Less than 1%
What if?

“Integrate” a form of compaction or stiffness (load bearing strength) measurement

Get real-time, infinite (complete jobsite) data

Early indications of non-uniformity or soil unsuitability
a) Fundamental Frequency  
b) 2nd Harmonic Frequency  
Soil Stiffness indicated as a ratio of b:a
Definitely an improvement versus point testing methods, but with a few downsides:

1. Soil types (variability in cohesive)
2. Measurement depth (deeper than lift thickness)
3. Vibratory settings ("blind" without vibration)
Energy Based

Relate to the physical properties of the material being compacted, using machine energy as an indicator.

Improve on the “downsides” of the accelerometer-based technology.

ROCK  SAND AND GRAVEL  SILT  CLAY

PAVING ALL DAY. EVERY DAY.
Temperature

Not a direct measure of compaction, rather, data for **process control** on asphalt

- Dual infra-red sensors mounted on the front and rear of machine deliver real-time readings
- *Keep operator informed* of when to begin rolling and when to stop
- *Help avoid tender-zones* that often occur in the 104º to 110º C (219º to 230º F) temperature range
- Eliminates hand-held devices
“Vision of the Future”

Current/historic state to ensure adequate performance:

a) process control (lift thickness and # of passes)
b) end-result spot devices to ensure compaction and moisture

Disadvantages, include

a) measurements for only a small percentage of the working area
b) requires construction delays to allow for testing
c) results in downtime for analysis and
d) causes safety issues because of personnel in the vicinity of equipment
e) Timing of results/data – may be too late to do anything about it?
IC defined as a combination of:

a) Integrated compaction measurement technology (and other machine parameters, e.g., temperature)

b) Jobsite positioning data tied to the measurements being recorded

c) Ability to store and analyze the data collected to document for future purpose
Positioning Data
via GNSS Mapping Capability

• Utilizes Global Navigation Satellite System (GNSS)
  – GPS, GLONASS

• Correlates measurements to a location
  – Compaction, frequency, pass count, temperature, etc.
  – Documents work
  – Can provide picture of overall compaction consistency

• Choice of accuracy
  – SBAS: provides accuracy to 1 meter; this is the standard package
  – RTK – provides millimeter accuracy; this is an upgrade to standard package
Intelligent Compaction on Asphalt

Make Every Pass Count

PAVING ALL DAY, EVERY DAY.
What does it take to compact asphalt?

Machine – static and dynamic forces
- Machine mass - static forces PLI
- Vibratory systems – dynamic forces
  - flexible amplitude range and frequencies

Operator – performs the rolling pattern
- Where did I stop on the previous pass?
- Did I go back far enough on the return pass?
- Did I provide enough overlap on the previous pass?
- Is the mat temperature too hot, too cold?
- Night paving?

Distractions, fatigue, and multi-tasking can affect how well an operator executes the rolling pattern on an asphalt mat.
Rolling Pattern Challenges

Maximize Efficiency – Monitor Starts and Stops

- Blue color indicates the compactor traveling too far onto the previous pass – inefficient
- Red color indicates the compactor stopped short of the complete pass – improper pattern

Complete Pass
Overlap
Fresh Mat
Incomplete Pass
Mapping Passes

This illustration provides the pass-count mapping that occurred in the Minneapolis Global Paving parking lot. The colors signify the number of times that the drums hit a specific area.

Green – Target pass-count was met
Blue – Target pass-count not met; 1 more passes needed
Red – Target pass-count not met; 2 more passes needed

* Note: The red slivers within the paved areas indicate that there wasn’t proper drum overlap
Why is Pass-Count mapping important?

Pass-count mapping helps achieve target density and increases roller efficiency. With proper pre-project planning including machine selection, vibratory selection and speed, the operator can execute the rolling pattern in the most efficient manner possible.

- Eliminate excessive overlap
- Prevent incomplete passes, stopping short or missed
- Maximize coverage
- Easier night-time operation
Mapping Temperature

This illustration provides asphalt temperatures as the roller passed over the fresh mat. The color pattern signifies the different temperature ranges that were present.

Green – optimum temperature met
Blue – Target temperature met, lower range than green
Red – Temperature below target
Why is temperature important?

Understanding the asphalt temperature helps operators determine when the asphalt can be compacted.

- Upper temperature limit that permits compaction is normally around 149°C (300°F)
- Lower limit that permits compaction is normally around 85°C (185°F)
- Avoid “tender zones” if one is present
Compactor Data Collection

Data Collection - Parameters

The Compaction Control system displays and records the following:

- Machine Position (GNSS)
- Machine Pass Count/Coverage
- Compaction Width
- Asphalt Temperature
- Compaction Measurement (soils)
- Vibratory Status (on/off/rear/both)
- Vibratory Frequency
- Machine Speed
- Direction or travel (forward, reverse)
Now, what do we do with all the valuable data that we have created and collected?
Data Management

- Optional packages to download compaction data for analysis and creation of reports for QC/QA, DOT approval, archives for future reference, etc.

- “Key to unlock the value” of Intelligent Compaction
So what? How does this benefit us?

Quality Control & Process Control

• Increased Operator Awareness
  – Real-time compaction (soils), temperature (asphalt), pass count data, early notice of problem areas, etc.
• Improved Density & Smoothness (asphalt)
  – Better understanding of mat conditions
• Improved Rolling Pattern (asphalt)
  – Optimized pass coverage; easier night-time operation
• Lower Operating Costs
  – Maximized machine utilization with better efficiency
• Documentation
  – Quality control and post-process data analysis
Example of the benefits of IC

Asphalt Compaction
Rolling Patterns
Recorded Data

Pass #1 of pattern
- GREEN: Vibe ON
- RED: Vibe Ramping
- PINK: Vibe OFF
Recorded Data

Pass #2 of pattern
Vibe engaged to roll through pass #1 OFF location
Recorded Data

Pass #3 of pattern
Note the timing of the vibe OFF location
Recorded Data

Pass #4 of pattern
Vibe ON location correct to roll through previous vibe OFF location
Recorded Data

Pass #5 of pattern
Beginning of next pattern
Note the location of previous stops
1-Roll out & Stop Angle

1-Vibe OFF

Pass #1 of pattern
Existing vibe OFF and Roll-out/Stop Angle
Roll-Out & Stop Angle

Pass #1 of pattern
Correct Roll-Out and Stop Angle

1-Correct Roll out & Stop Angle

1-Vibe OFF
Pass #3 of pattern
Note vibe OFF and Roll-out/Stop Angle
Pass #3 now rolls the stop mark out of Pass #1 correct stop and angle
Still incorrect in regards to vibe OFF and Roll-Out/Stop Angle
Pass #3 of pattern
Correct vibe OFF and Roll-Out/Stop Angle
Vibe completely through existing stop mark of Pass #1
Roll-Out and Stop Angle ready for Pass #5
Pass #5 of pattern
Note correct Roll-Out and Stop Angles with regard to previous passes

3-Correct Roll out & Stop Angle

1-Correct Roll out & Stop Angle

3-Roll out & Stop Angle

3-Correct Vibe OFF

5-Vibe through to next pattern
Summary

1. Intelligent Compaction (IC) provides benefits over traditional testing methods:
   i. Increased Operator Awareness
   ii. Improved Density & Smoothness (asphalt)
   iii. Improved Rolling Pattern (asphalt)
   iv. Lower Operating Costs
   v. Documentation (statistically significant)

2. IC includes:
   i. Compactor integrated data measurement
   ii. GNSS Positioning tied to collected data
   iii. Ability to analyze & document data

3. IC on Soils is more a direct measure of compaction

4. IC on Asphalt is more process control at this point

5. Data (types) and documentation is the future (QA?)
Questions?

PAVING ALL DAY. EVERY DAY.
Back-up Slides
Entry level offering with unmatched integrated differentiation

- Machine Drive Power
- Automatic Drum

Scalable system architecture for factory or field upgrades

- GNSS Mapping with integrated design (MS952) offering more robust design and theft/vandalism deterrent
Intelligent Compaction (soil - CMV)

- **Accelerometer-based**
  - Comparable to technology widely available in industry
  - For use on granular soils only
  - Dampening effect of cohesive soils and silts makes CMV unsuitable for use with padfoot drums
  - Measures 1 to 1.2 meters (39 to 48 in) deep
  - Vibe system must be activated to work

- **Benefits of technology:**
  - Measures a large volume of soil
  - Can reveal undesirable objects buried deep in soil: tree trunks, tires, clay balls
Intelligent Compaction (soil - MDP)

- **Energy-based**
  - Measures rolling resistance to determine soil stiffness; a more direct measurement
  - For use on both smooth drum compactors and padfoot compactors
  - Works on all soil types: granular and cohesive
  - Works with vibe system on or off
  - Measures 30-60 cm (1 – 2 ft) deep

- **Benefits of technology:**
  - Measures closer to the depth of the material you are working
  - Widest range of applications
  - Correlates better to portable measurement devices
Compaction Measurement Review (soil)

Accelerometer Based
Compaction Meter Value method (CMV & CCV)
- Drum mounted accelerometer measures G-force at vibratory frequency and harmonics. (typically vertical accelerations only)
- CMV measurement is a dimensionless unit that is an indicator of stiffness (ratio of first harmonic and fundamental frequency)
- Requires vibration and is not recommended for padfoot configuration (cohesive materials)
- Depth measured by a vibrating drum is greater than that of most all other devices and is highly variable
- Can be combined with other available GPS technology to map and store data
- Different suppliers and users of this method of technology to measure soil stiffness over the years

Energy Based
Machine Drive Power (MDP) method
- Measures driveline power used to roll over soil with corrections made for grade and machine acceleration.
- MDP measurement value is a dimensionless unit that is an indicator of stiffness with much less variation as compared to accelerometer based measurements (indicated by vehicle rolling resistance)
- More flexible: Works on both vibratory and non-vibratory compactors; as well as with cohesive vs composite materials (padfoot drum vs smooth drum)
- Depth measured is more closely related to thickness actually being compacted and thus more easily correlated to other types of stiffness tests (plate load)
- Can be combined with other available GPS technology to map and store data-either from the factory or in the aftermarket
- Patented technology only available on Caterpillar B-Series Soil Compactors
Intelligent Compaction (asphalt - temperature)

1. Receiver and Angle Sensor
2. Air purged Infrared Temperature Sensor
3. Display
4. Radio – only for high accuracy mapping
Intelligent Compaction (asphalt)

Operator Display

- Display provides real-time pass-count and temperature readings
- Operator can see where he/she is on the mat and how many passes have been made
- Operator can determine when to begin rolling and when to end, based on mat temperature

A warning indicator alerts the operator if the asphalt temperature exceeds or falls below the target temperature
Intelligent Compaction (GNSS positioning)

- **Choice of two technologies**
  - Compaction Meter Value (CMV)
  - Machine Drive Power (MDP)
- **Outputs real-time compaction data to integrated LCD display**
- **System can be augmented with Global Navigation Satellite System (GNSS) mapping capability**
  - SBAS or RTK accuracy
  - Requires display and hardware
- **Flexible options**
  - Scale system capability to needs
  - Wide range of applications