Implementation of Electro-Magnetic Gauge Readings for Assessing Hot Mix Asphalt Quality

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Quality Assurance

- Varies from one agency to the another
- Density often an indicator
- Traditionally:
  - Cores pulled from multiple locations
  - Density checked by contractor or owner/agency
- Other methods
  - Nuclear Gauges
  - Non-Nuclear Gauges

Quality Assurance

- Bulk Specific Gravity
  - Air Voids (AV)
  - Voids in the Mineral Aggregate (VMA)
  - Voids Filled with Asphalt (VFA)
  - Density (% Gmm)
- While only 1 of 31 states directly specifies Bulk Specific Gravity, all but 2 of 31 use it by specifing AV, VMA, or Density (Burati et al., 1999).

Saturated Surface Dry

- AASHTO T 166 or ASTM D 2726
- Most common method for determining the bulk specific gravity
- Dry weight, submerged weight, and saturated surface dry weight
- Not appropriate for coarse mixes
  - Interconnected air voids
  - Significant surface irregularities

Paraffin and Parafilm Method

- AASHTO T 275 and ASTM D 1188
- Samples with open or interconnected air voids
- Weight of uncoated in air, coated in air, and coated in water
- Film/Wax prevents future use of specimen
- Film/Wax is messy

Vacuum Sealing Method

- ASTM D 6752
- Weight of specimen in air, bag, sealed specimen in air, and sealed specimen in submerged
- Good for coarse mixes

Nuclear Gauges

- Most common non-destructive method
- Not as accurate as core densities
- Quick and limited human interaction
- Special training and certification
- Many studies concluded only good for quality control

Non-Nuclear Gauges

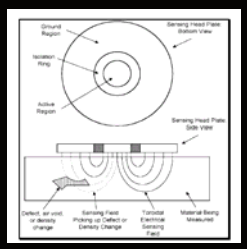
- Electro-magnetic
- Non-destructive devices
- Commercially available 1998
- Pavement Quality Indicator (PQI)
- PaveTracker
- No special training or certification

Pavement Quality Indicator

- Trans-Tech Systems
- Measures changes in electrical impedance of material
  - Function of composite resistivity and dielectric constant of material
- Electrical field produced by electrical charge
- Measure strength of electric field

Concept Behind Non-Nuclear Gauges

- As pavements become more dense:
  - ↓ air volume: other components volume
  - Δ dielectric constant
  - Δ electrical signal
- Only component changing is air



NCHRP, 1999

PaveTracker

- Troxler Electronics Lab

Field Sites- 2006 Paving Season

- 15 field sites
- 3 Aggregate types
  - 2 slag/limestone
  - 2 quartzite
  - 11 limestone
- 12.5 or 19.0mm NMAS
- Low and high volume traffic levels
- 2" to 6" lifts

www.mii.org

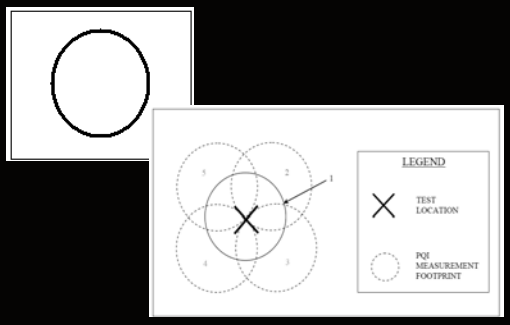
www.turnstone.ca

www.mii.org

Field Sites, Cont.

Site Name	Paving Contractor	Aggregate	Binder	NMAS(mm)	Traffic
1	1	Limestone	4.34	19.0	30000000
2	2	Slag/Limestone	6.18	19.0	1000000
3	4	Limestone	5.30	12.5	1000000
4	4	Limestone	5.91	12.5	300000
5	5	Limestone	5.47	12.5	1000000
6	6	Limestone	4.94	12.5	3000000
7	7	Limestone	5.60	12.5	3000000
8	1	Limestone	5.89	12.5	30000000
9	3	Quartz	4.65	12.5	30000000
10	4	Limestone	5.40	12.5	3000000
11	4	Limestone	6.20	12.5	1000000
12	4	Limestone	5.80	12.5	1000000
13	1	Limestone	6.10	12.5	1000000
14	2	Slag/Limestone	5.61	12.5	10000000
15	3	Quartz	5.10	19.0	30000000

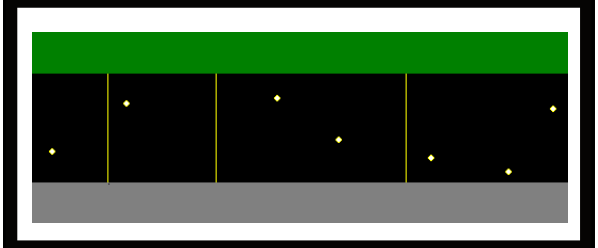
Pavement Quality Indicator



PaveTracker

NYDOT, 2003

Reading Locations



Testing

- PQI
  - Single readings every 1 ft
  - 1 Random reading per location (cloverleaf)
  - All readings dry except for final random reading per station
- PaveTracker
  - Four readings every 1 ft
  - All readings dry except a random wet reading per station

Pavement Conditioning

- Most readings were dry
- Wet readings were collected last
- Approximately 10 oz. poured on pavement

Readings

- PQI
  - Cloverleaf
  - Four overhangs
- PaveTracker
  - Four turns
  - No overhangs

www.TroxlerLabs.com , 2007

www.transtechsys.com, 2007

What is of Interest?

- Sensitive to roller passes?
- Sensitive to the presence of moisture?
- Sensitive to aggregate?
- Similar to cores?
- Similar to one another?
- Same mixes passing as cores?

Analysis Tools, Cont.

- Why look at ANOVA and Regression?
  - ANOVA evaluates class variables
  - Regression relates significance and relationship of class and continuous variables
  - Class variables are easier for contractor to control or know ahead of time
  - Example: Aggregate type is known before paving begins, however, asphalt content could vary from JMF

Analysis Tools, Cont.

- Difference between regression/ANOVA and mean comparisons:
  - Regression and ANOVA evaluate the significance of a variable
  - Mean comparisons evaluate differences between levels within a variable
  - Example: Regression/ANOVA deems density device significant, but mean comparisons relates which density devices yield statistically different results

PaveTracker ANOVA

- Data collected every foot
- Affect density readings?
  - Site
  - Random Station
  - Pavement Condition
  - Contractor
  - Aggregate Type
  - NMAS
  - Roller Pass
  - Distance Across Pavement

PaveTracker Regression

Important
- Station
- Pavement Condition
- Contractor
- Aggregate
- Binder Content
- NMAS
- Roller Pass

Not Important
- Site
- Traffic Level
- Pavement Width
- Transverse location

PaveTracker Field Mean Comparisons

- Site (15 Levels)
- Pavement Condition (2 Levels)
- Contractor (7 Levels)
- NMAS (2 Levels)
- Traffic Level (5 Levels)
- Aggregate Type (3 Levels)
- Roller Pass (3 Levels)

PaveTracker Field Mean Comparisons

- Site
  - 3 sites significantly different
  - Failing subgrade (1), slag (1), ? (1)
- Pavement Condition
  - Wet significantly different than dry
- Contractor
  - 2 significantly different
  - Slag (1), only 1 mix collected (1)

PaveTracker Field Mean Comparisons, Cont.

- NMAS
  - No differences
- Traffic Levels
  - All different
  - Related to gradation perhaps
- Roller Pass
  - All different
  - Gauges sensitive to changes in density

PaveTracker Field Mean Comparisons, Cont.

- Aggregate type
  - Slag significantly different than limestone and quartzite
- Station
  - Differed
  - Changes in subgrade?
  - Changes in roller pattern/frequency?

Single Mode PQI Field Regression

Important
- Station
- Pavement Width
- Distance Across Pavement
- Pavement Temperature

Not Important
- Site
- Contractor
- Aggregate Type
- Binder Content
- NMAS
- Traffic Level
- Roller Pass

Single Mode PQI Field Mean Comparisons

- Site
  - Slag (2) and sampled once (2)
- Contractor
  - Almost all
- NMAS
  - None
- Traffic Level
  - Almost all
- Aggregate Type
  - Slag
- Roller Pass
  - All

Multi-Mode PQI Field Regression

Important
- Site
- Width
- Contractor
- Aggregate Type
- Binder Content
- Roller Pass
- Distance Across

Not Important
- Station
- Condition
- NMAS
- Traffic Level

Multi-Mode PQI Field Mean Comparisons

- Site
  - Slag
  - 4 significantly different
- Contractor
  - Most
- NMAS
  - None
- Traffic Level
  - Most
- Aggregate Type
  - No difference
- Roller Pass
  - All but Final and 2nd to last
- Pavement Condition
  - Wet different than dry

Significant Variables for Both Single and Multi-Mode PQI Field

- ANOVA
  - Site, station, roller pass, and distance across a pavement
- Regression
  - Station, pavement width, and distance across a pavement

Significantly Different Levels

- Site
  - 3 sites deemed statistically different than the others
  - Additional uncommon sites were identified
- Contractors
  - Single Mode: Almost all
  - Multi-Mode: 3 different
- NMAS
  - Single and Multi- Mode: None
- Aggregate Type
  - Single Mode: Slag different
  - Multi-Mode: None

Reason for Differences

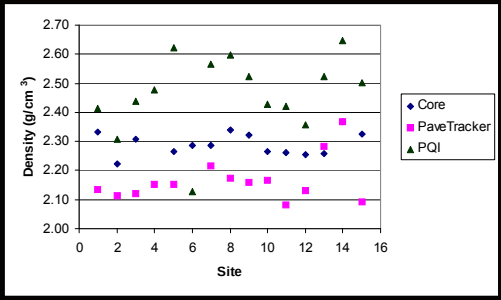
- Multi-Mode only looked at one spot per station
  - Compared to 12-24 locations per stations for single mode
- Single mode has more data
  - Outliers less likely to affect analysis and quality/density assessment

Core Readings

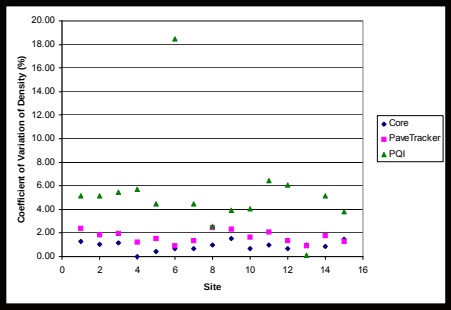
- Typically 7 cores pulled per site
- Compared core densities to gauge densities
- Core density used as control

www.hawaiiasphalt.com, 2007

Mean Density Comparison



Coefficient of Variation



Analysis

- PQI almost always the most variable
- PQI yielded the highest values in most cases
- PaveTracker almost always the lowest values
- Coefficient of variations are the most similar for cores and PaveTracker

Field Conclusions

- PQI yields higher mean densities
- PQI yields higher standard deviation
- Sensitive to roller passes
- Both PQI and PaveTracker have issues with pooled water

Quality Assurance Conclusions

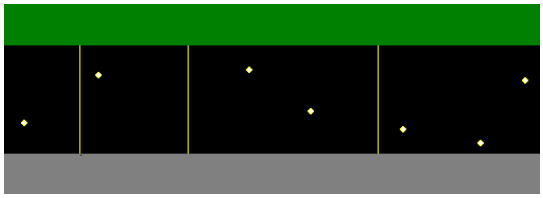
- PQI resulted in passing almost all of the same sites as cores without a correction factor
  - Not PaveTracker
- PaveTracker agreed with cores once correction factor applied
  - Not PQI

➢ Gauges will need to be calibrated against field cores.

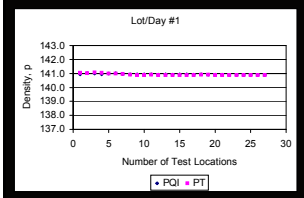
2nd Phase- 2007 Paving Season

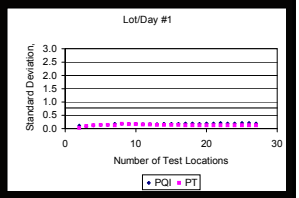
- Evaluate core and electro-magnetic gauge adjustment factors
  - Are the adjustment factors the same from one paving day to the next?
  - How improved are the latest electro-magnetic gauges?
- We are confident the technology can be implemented for QA/QC
  - How many readings are needed to represent at least the same assessment of quality as cores?
  - What is the trigger for re-establishing the adjustment factor?

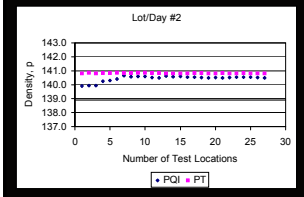
Electro-Magnetic Gauge Testing

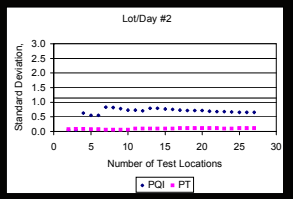


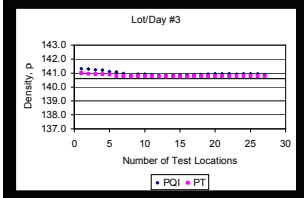
19mm Limestone
75mm Paving Lift

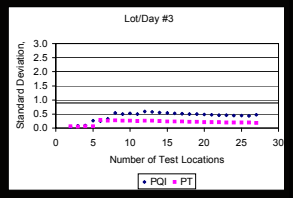


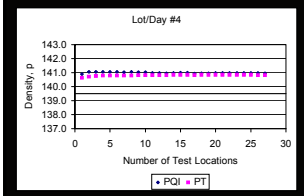


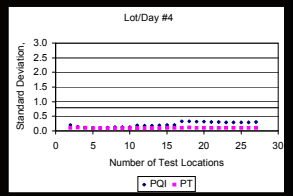


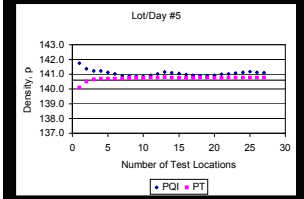


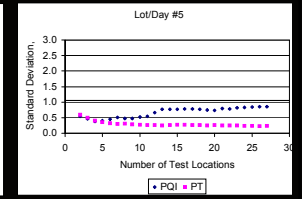




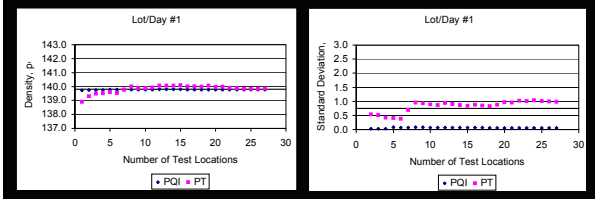


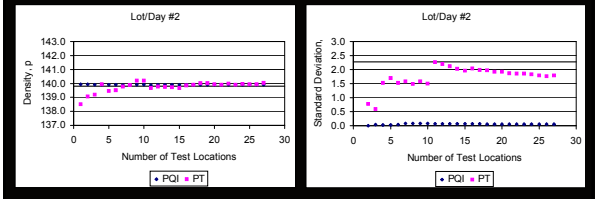


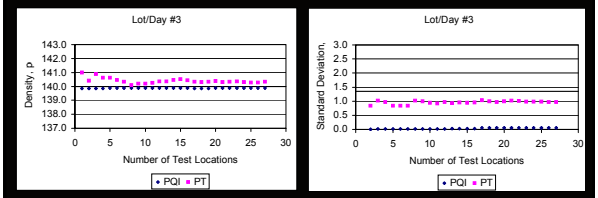


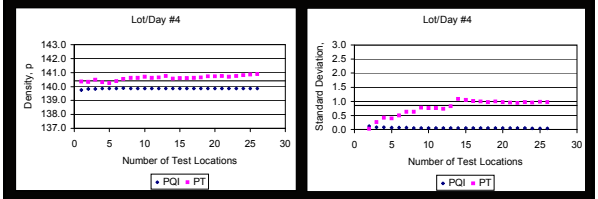


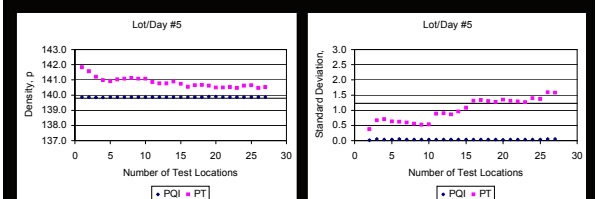
12.5mm Limestone 50mm Paving Lift



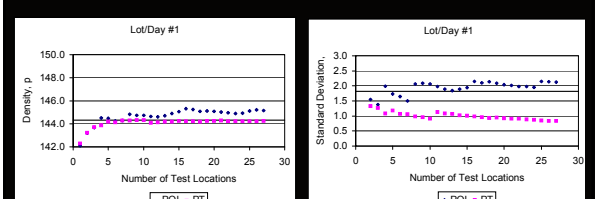


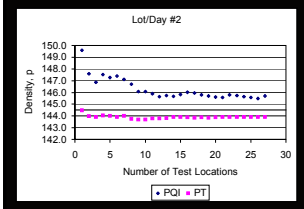


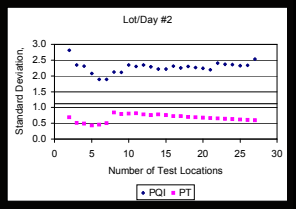


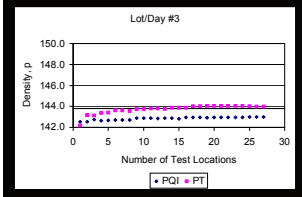


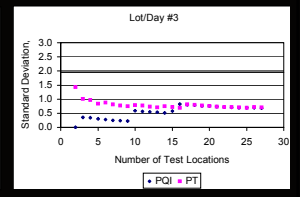
12.5mm Gravel 50mm Paving Lift











Outcomes of Phase 2 Work

- We can overcome issues identified in the 1st phase by calibrating gauges with cores from first day of production and use on ensuing days of production.
- Two options:
  - Gauge identifies non-compliance- verify with cores.
  - Calibrate gauge with reduced number of cores daily and use more gauge readings for quality assurance program.
- PaveTracker appears to be preferred over the PQI.

Next Steps

- Developing shadow specification for use in the upcoming construction season in existing QC/QA program
- Updated for inclusion in percent within limit specifications

Other Technologies Being Considered by DOTs

- Corelok for density testing
- Permeability
  - NCAT permeameter
  - Falling head permeameter (Karol-Warner)
  - ROMUS permeameter

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Questions?