Advances in
Intelligent Compaction of AC Pavements

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February 20, 2007

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IC for Soil Compaction

Intelligent Compaction became popular in the early 70's primarily as a tool for determining the modulus of soil during compaction. AMMANN (Automatic Compaction), BOMAG (VARIO Control), and GeoDynamik (Compactometer) were the three companies that incorporated this technology in their products.

AMMANN Compaction Expert (ACE)

AMMANN Compaction Expert (ACE), is an electronic measuring and control system for vibrating rollers. ACE operates on the principle of automatically reducing the compaction energy as the bearing capacity of the ground increases.

ACE is mounted on both the front and rear drum of the vibratory compactor. The amplitude of the vibrations and their frequency are both adjusted to control the compaction energy.

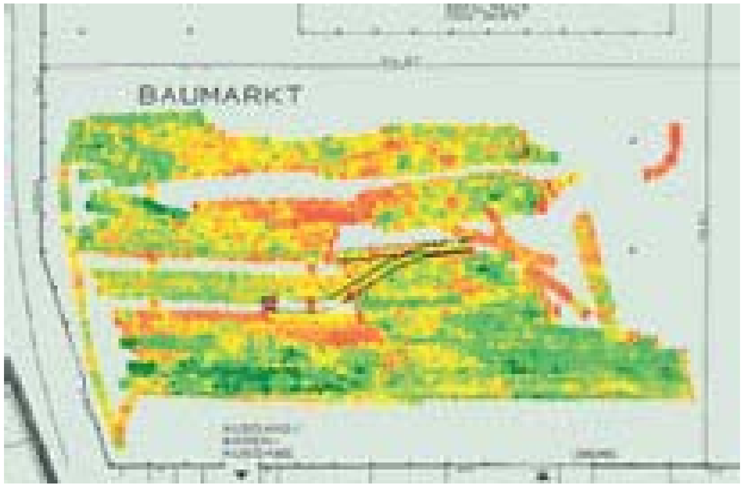
This Continuous Compaction Control (CCC) results in:

- areas with lower bearing capacity are compacted with a high effective amplitude,
- very hard areas are compacted with a low effective amplitude,
- the frequency is adjusted to the resonance of the ground,
- compaction is displayed in MN/m in the same way as for the plate loading test, soft points are identified.

from ACE – Ammann Compaction Expert, Intelligent Compaction Brochure,

http://www.ammann-group.ch

ACE Documentation System



Load Bearing Capacity

Number of Passes

Dynamic ground bearing capacity measurements are taken parallel to the control process (30 to 50 times per second!), to indicate the compaction condition of the ground. During compaction, the ground is subjected to a load and the associated subsidence is measured. These two items of information are used to determine the bearing capacity of the ground.

from ACE – Ammann Compaction Expert, Intelligent Compaction Brochure,

http://www.ammann-group.ch

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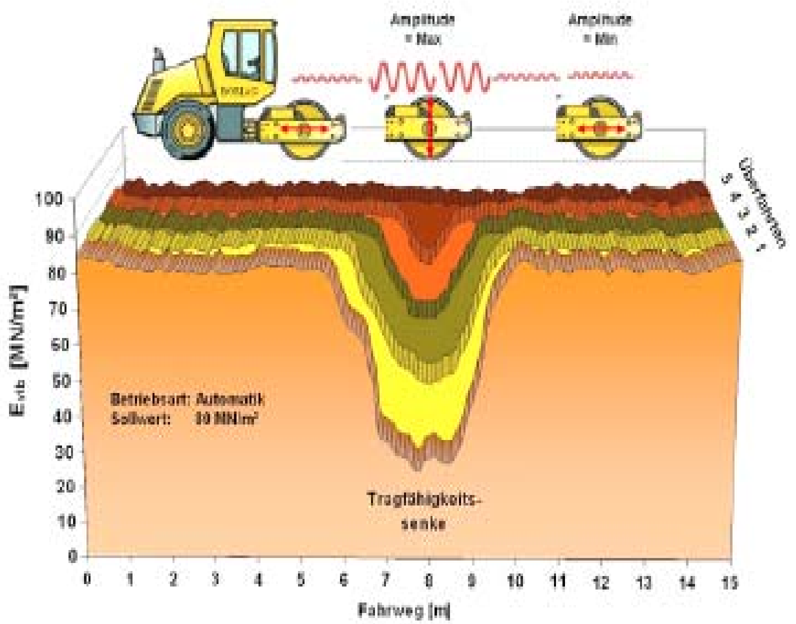
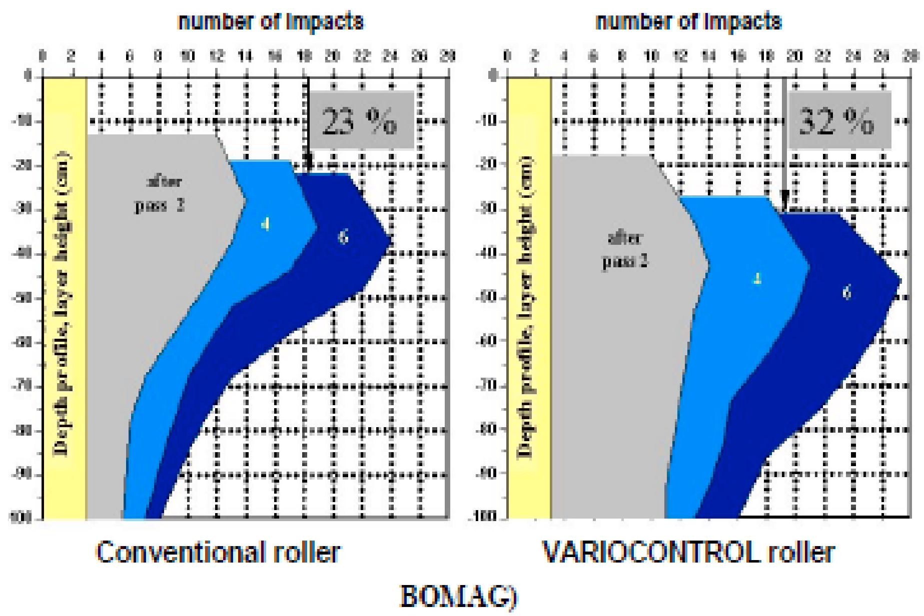
BOMAG VARIO Control





BOMAG Brochure, 2006

http://www.bomag.com/media/editor/WM9703_0403_rdr.pdf.

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BOMAG Operator Panel

PRINTER
- **Start**
- **Stop**
- **Print out**
- **Delete**

Test procedere:

- **Mark the track to be compacted**
- **„Manual operation mode“ with**
- **Fixed amplitude**
- **Fixed working speed**

From Chuck Deahl, Intelligent Compaction, NCAUPG HOT MIX ASPHALT TECHNICAL WORKSHOP AND CONFERENCE, January 2006.

Geodynamic (Compactometer)

Compaction meter value can be defined as

$$CMV \approx \frac{\hat{a}(2\omega_0)}{\hat{a}(\omega_0)};\ \hat{a}\ \textit{is the amplitude};\ \ \omega_0\ \ \textit{is the excitation frequency}.$$

It is assumed that the amplitude of the force of the blows is proportional to the first harmonic of the acceleration and that the displacement is approximately the double integral of the fundamental acceleration component.

BOMAG Asphalt Manager

Advantages:

- Immediate determination of dynamic stiffness in MN/m²(E_{VIB})
- E_{VIB} can be correlated with the increase of compaction
- E_{VIB} is widely independent from roller parameters
- E_{VIB} printouts for area covering compaction control

In Development:

- Target E_{VIB} values to be pre-selectable
- "Ready" indication if target value is achieved (red light)
- "Ready" indication if no further compaction is possible (red light)

From Chuck Deahl, Intelligent Compaction, NCAUPG HOT MIX ASPHALT TECHNICAL WORKSHOP AND CONFERENCE, January 2006.

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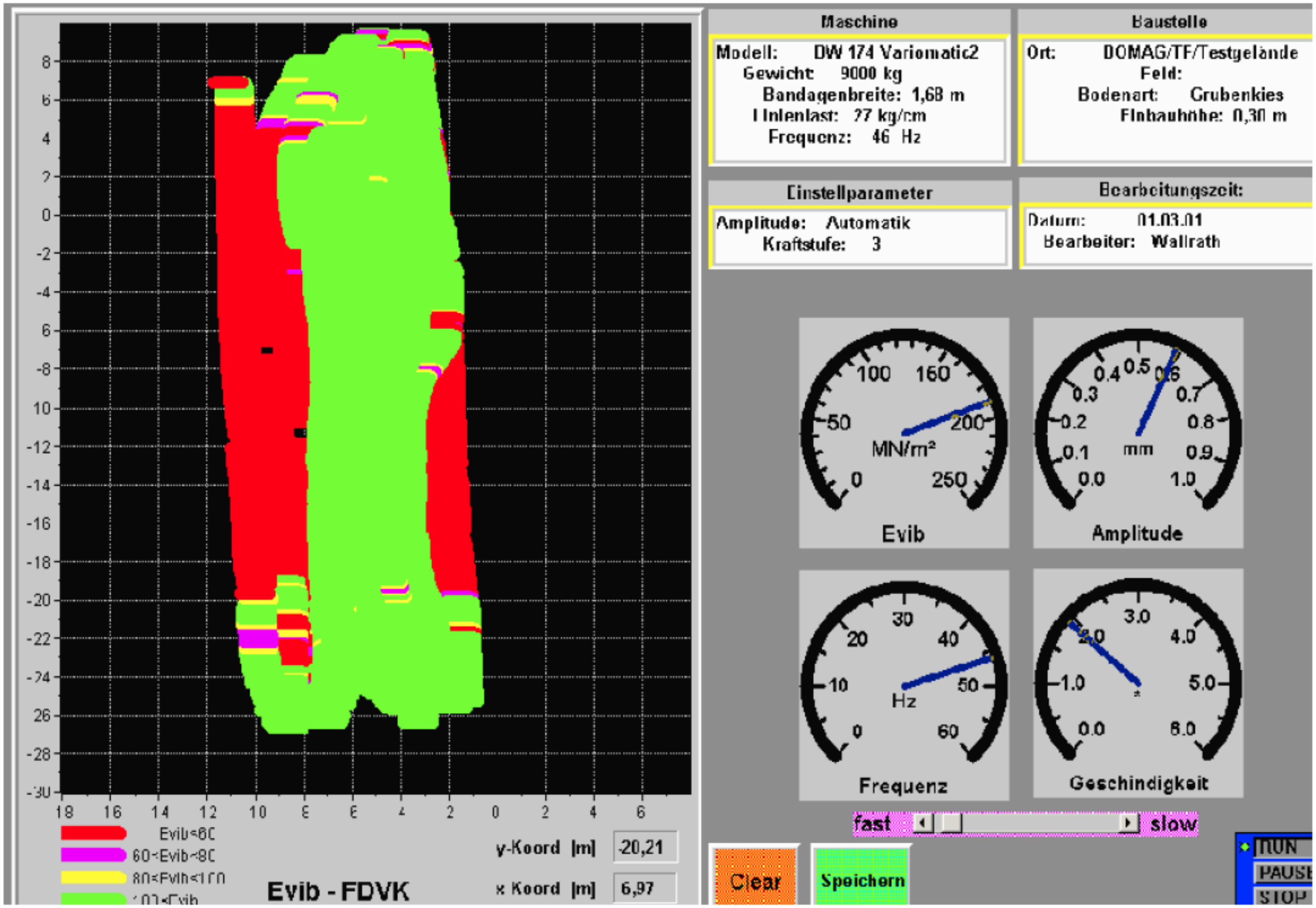
BOMAG Surface Covering Compaction Measurement



From Chuck Deahl, Intelligent Compaction, NCAUPG HOT MIX ASPHALT TECHNICAL WORKSHOP AND CONFERENCE, January 2006.

What is Intelligent Compaction (IC)?

Intelligent Compaction (IC) is the process of continuously controlling the operational parameters of a vibratory compactor to optimize compaction and meet required conditions.

The IC controls the different compaction parameters for the roller such as the frequency and amplitude of the vibrations of the drum, and the roller speed.

Key components of IC are a system to measure the stiffness of asphalt, sensors to monitor the location (GPS) and the operational parameters of the roller, and devices to record and display these data to the user.

Advantages of Intelligent Compaction

- Higher efficiency and increased productivity

  (More than 30% reduction in labor and fuel costs

  Reduction in the number of conventional spot tests

  Example: 75% reduction in QA testing (Sweden))
- Higher adaptability (thin/thick lifts, soft/stiff subgrades)
- Better quality resulting from uniform and optimum compaction
- Less crushing of the aggregates
- Complete coverage of compaction surface evaluation
- Dynamic measurement of soil stiffness
- Increased life of the equipment.

Disadvantages:

- It requires sophisticated equipment to survive in rugged, off-road conditions
- It requires operator training
- IC rollers are more expensive than conventional compactors.

From J.L. Briaud, J. Seo, Intelligent Compaction: Overview and Research Needs, December 2003.

http://www.webs1.uidaho.edu/bayomy/trb/afh60/IntCompaction_Briaud_September2004_.pdf

Motivating Factors for the Adoption of IC Technology

- Growing Infrastructure Needs
- Inadequate funds / staff
- Slow product delivery and delays
- Cost overruns
- Perceived lack of maintenance efficiency.

The following factors help make IC popular in Europe:

- Use of best value awards in the procurement process
- Design-build is the is the contracting method of choice
- Tools and techniques for performance contracting are well established
- Traditional QA/QC roles and responsibilities impede the effectiveness of performance contracting. In the new model, QA/QC rests with the contractor; owner QA is built into the process at various control points.
- Standards exist in several EU countries (Austria (RVS 8S.02.6); Germany (ZTVE StB94); Sweden (VAG 94); and Finland). France, Netherlands, and Ireland are set to announce their national standards soon.
- Warranties for pavement construction is well established (Material and Workmanship, Performance, Pavement Performance, Design-Build Finance Operate).

From J.L. Briaud, J. Seo, Intelligent Compaction: Overview and Research Needs, December 2003.

http://www.webs1.uidaho.edu/bayomy/trb/afh60/IntCompaction_Briaud_September2004_.pdf

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Intelligent Asphalt Compaction Analyzer

Intelligent Asphalt Compaction Analyzer (IACA) is a device that will take into account the process variables and in real-time, provide a measure of the compaction density achieved relative to a target density.

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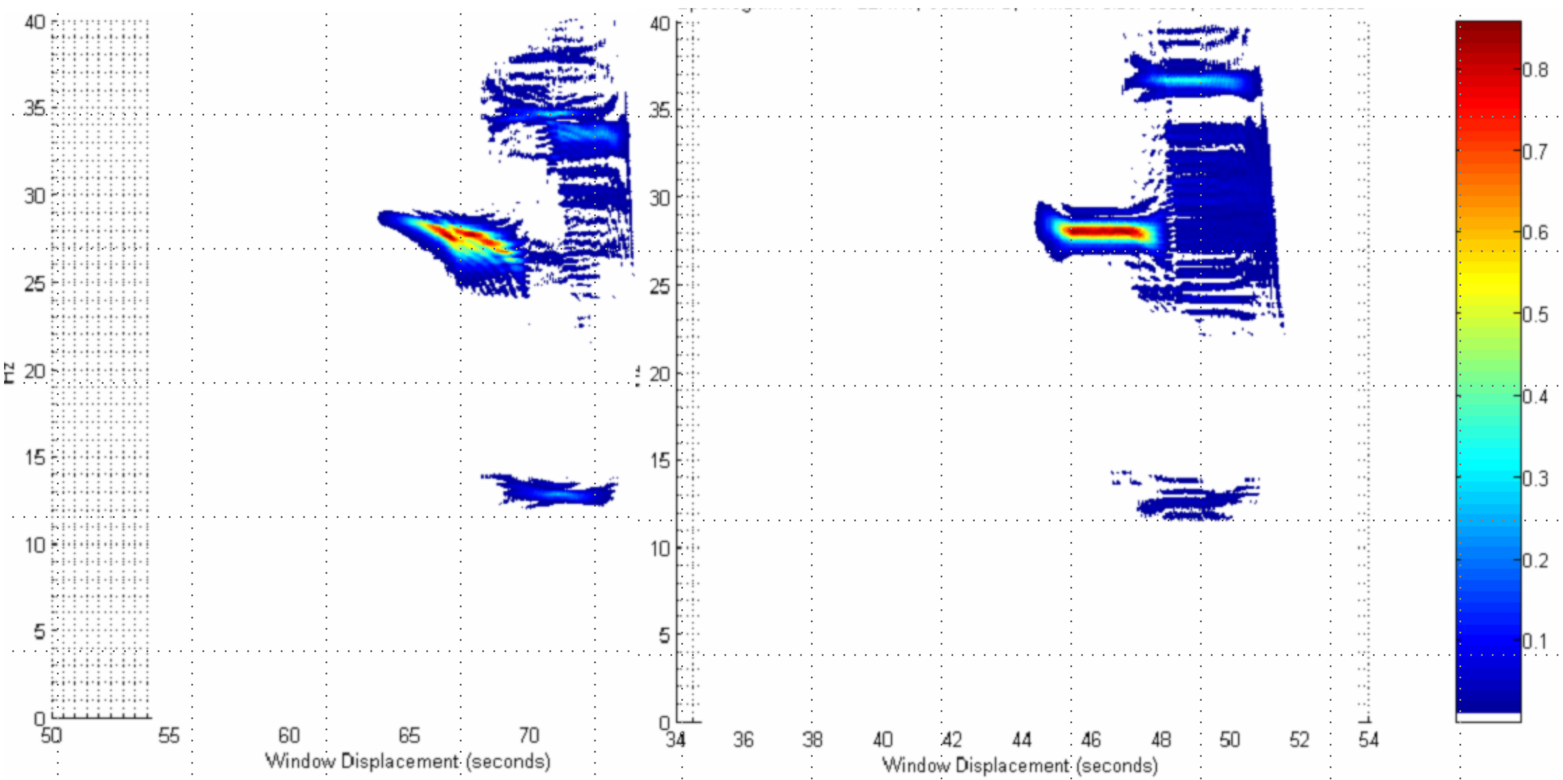
IACA Hypothesis

The Compactor, Hot Asphalt Mix, Base or Subgrade form a coupled system. The compaction density achieved can be predicted in real-time by analyzing the response characteristics of the compactor.

Spectral Analysis of Vibrations During Compaction



(a) Loose Mix Specimen

(b) Pre-Compacted Specimen

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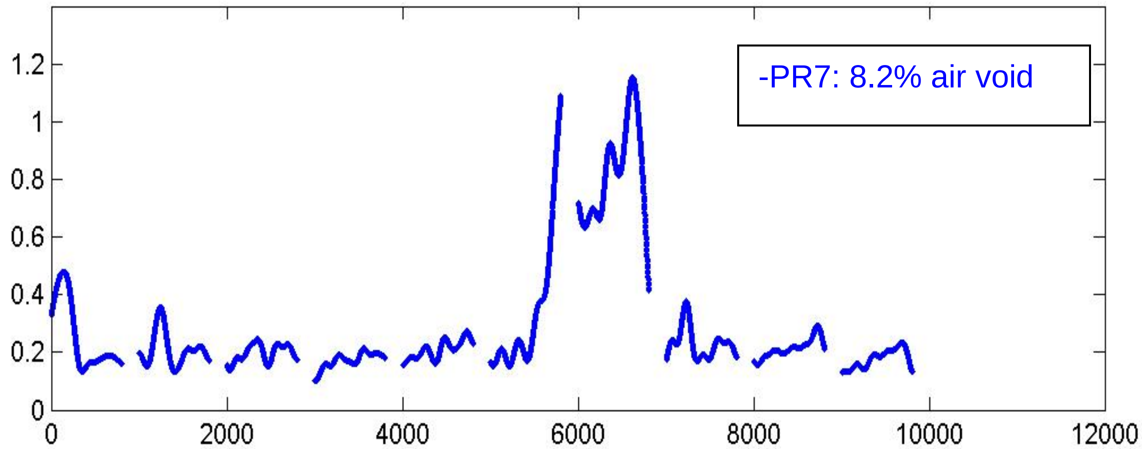
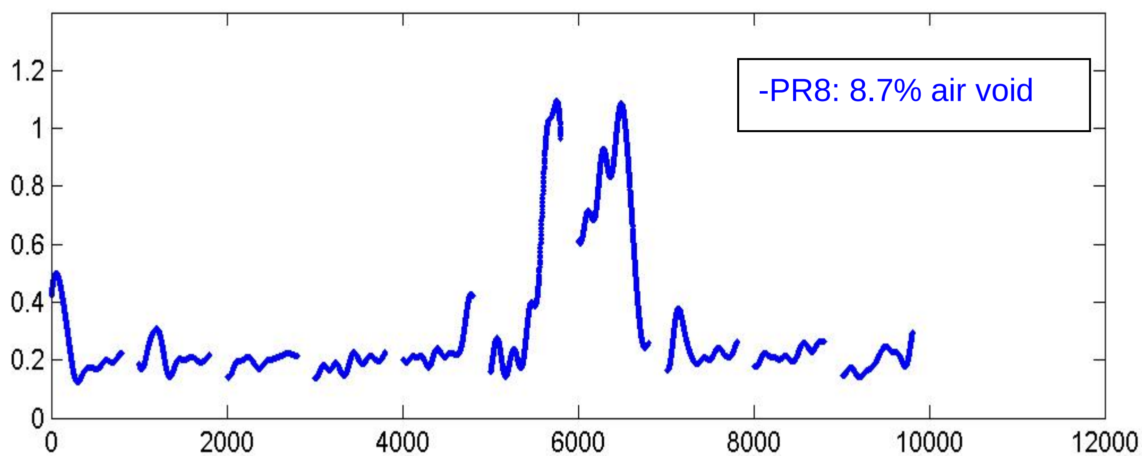
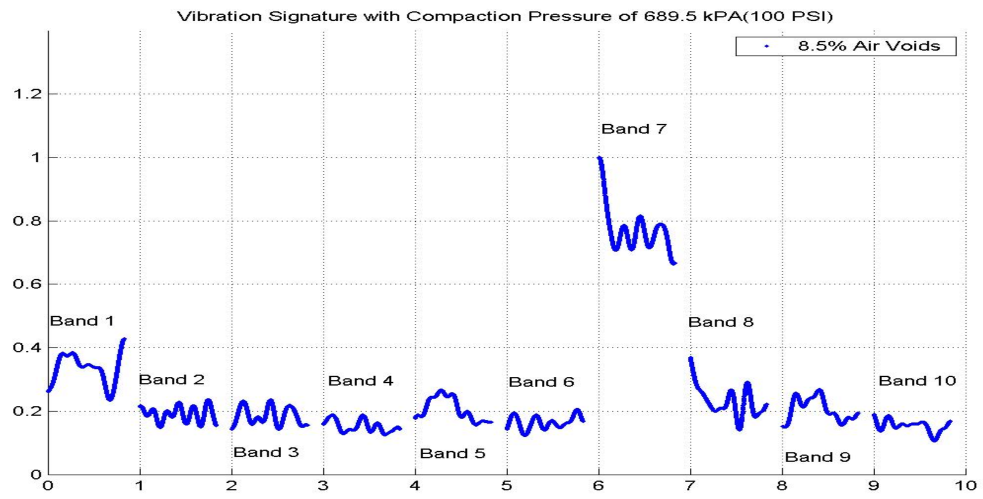
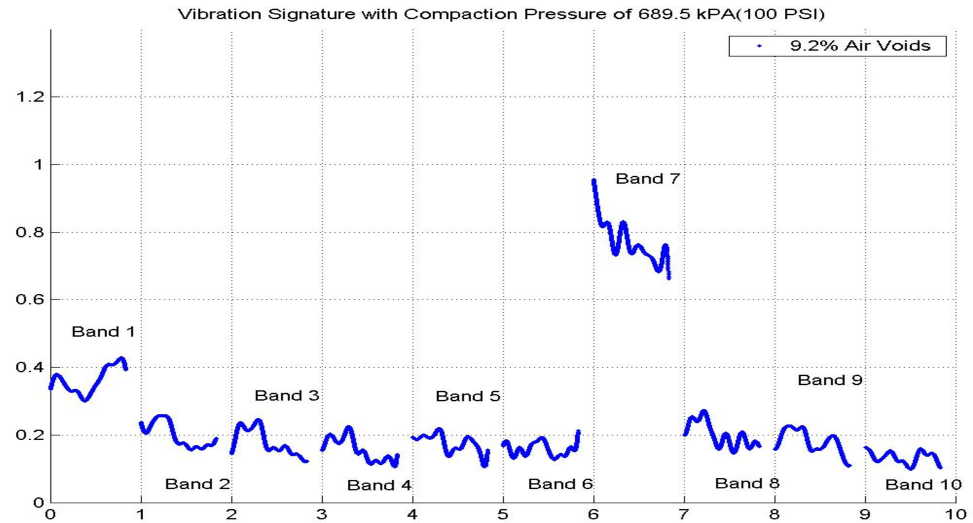
Vibration Signature with Compaction Pressure of 758.4 kPA (110 PSI)
compaction time = 60 s; Mix Temp.=152 ^{0}C ; 6.5 kgs (14.33 lbs)



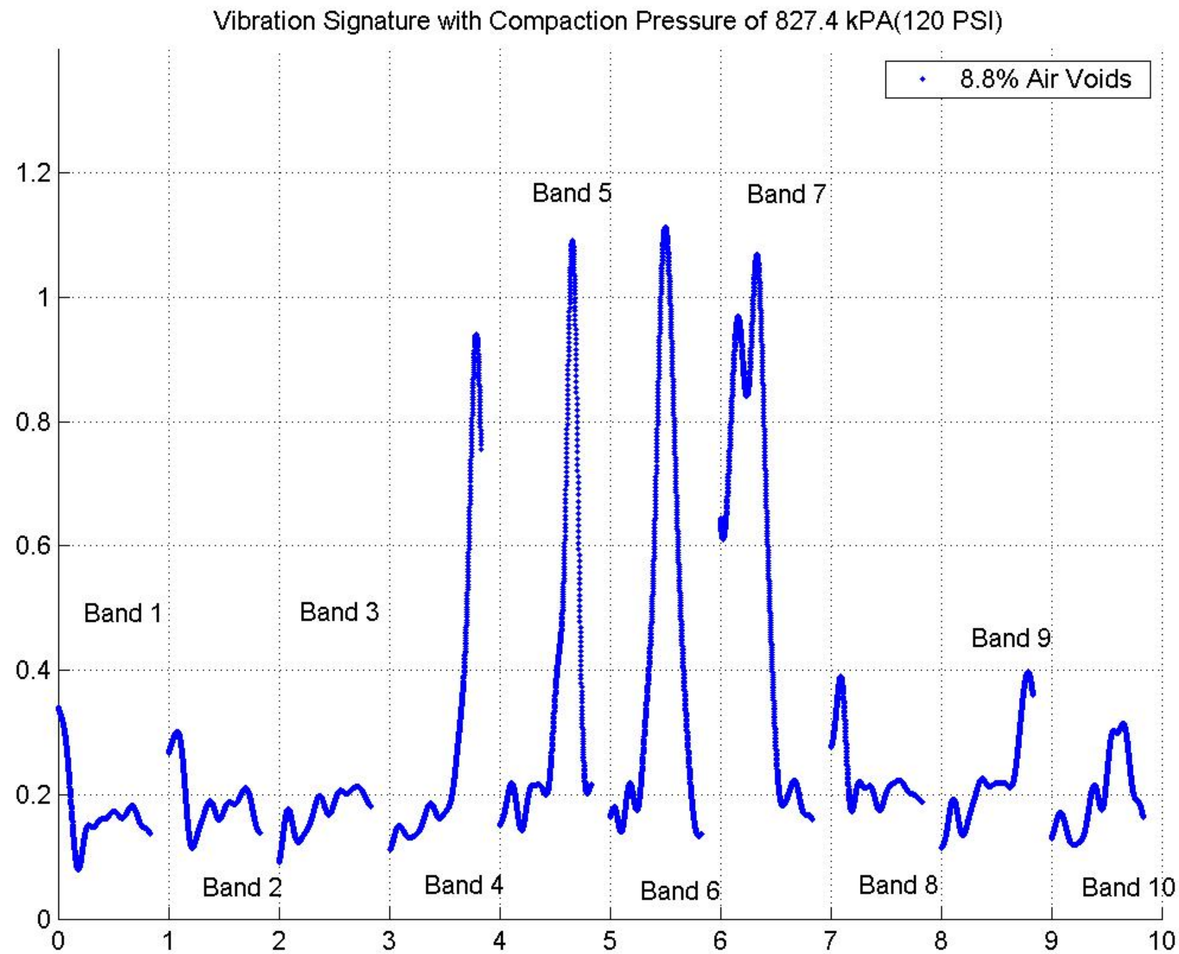


Effect of Compacted Density on Vibration Characteristics

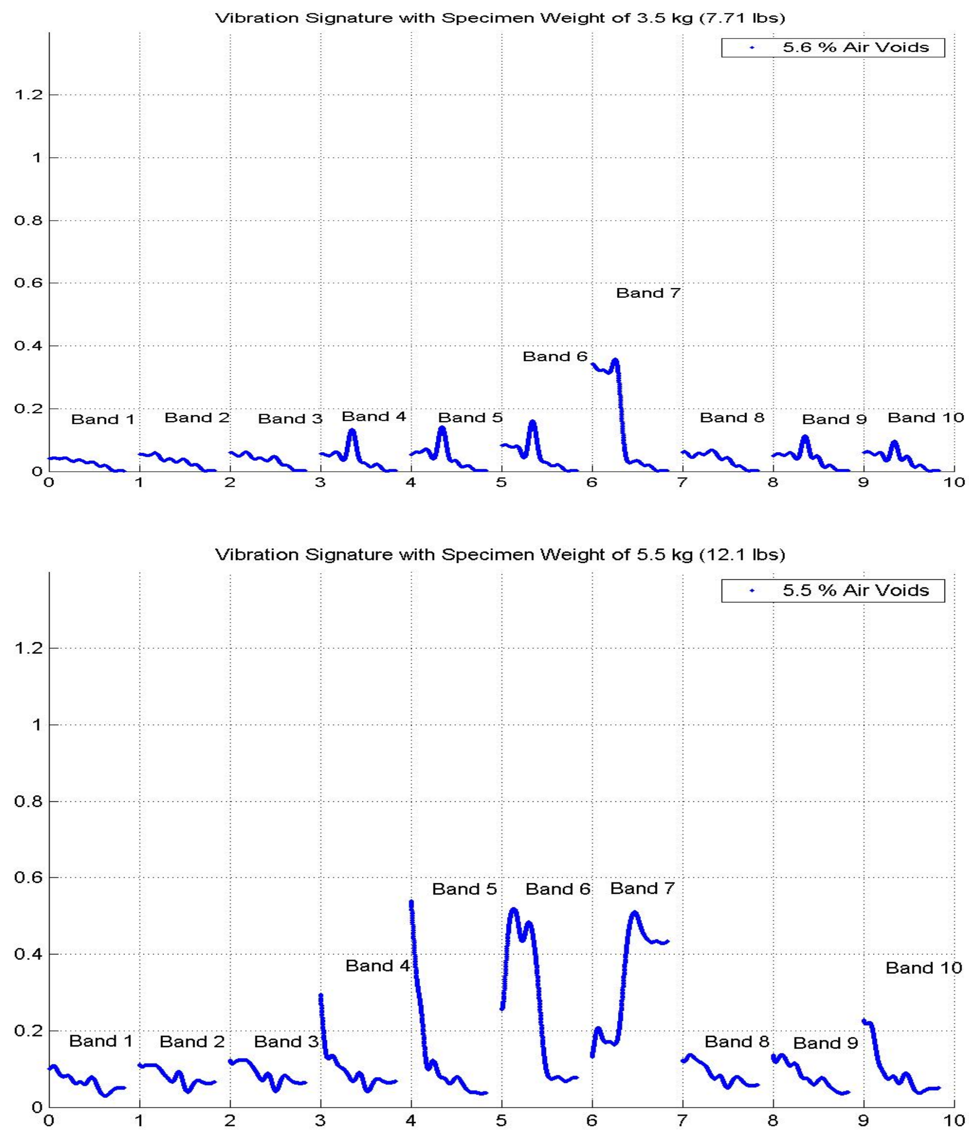




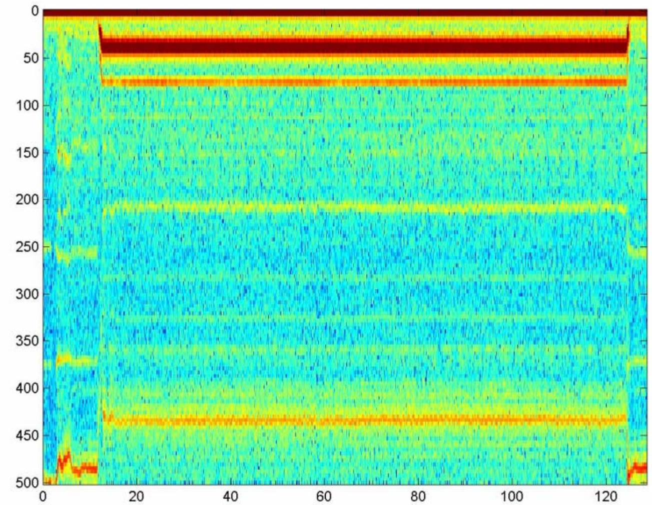
Effect of Compaction Pressure on Vibration Characteristics



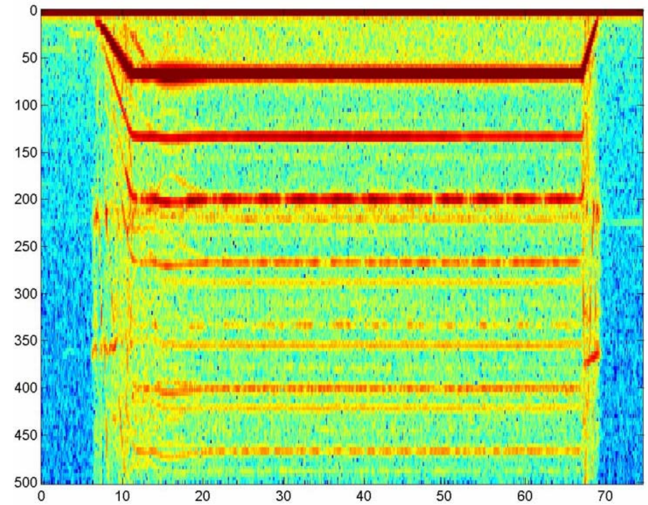
Effect of Lift Thickness of Vibration Characteristics



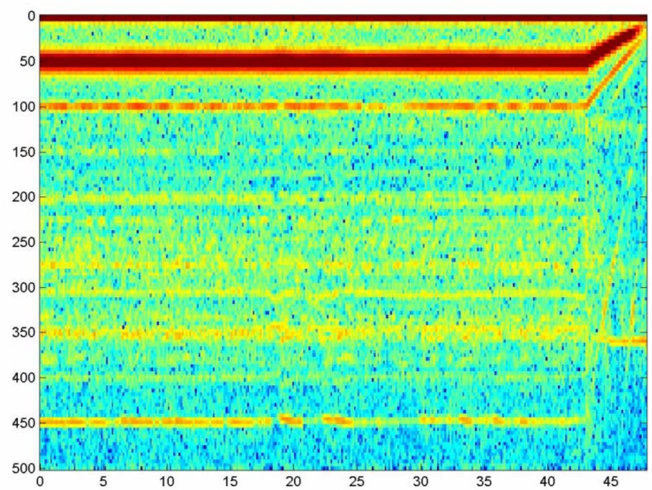
Field Compaction Results – Effect of Subgrade / Pavement Design



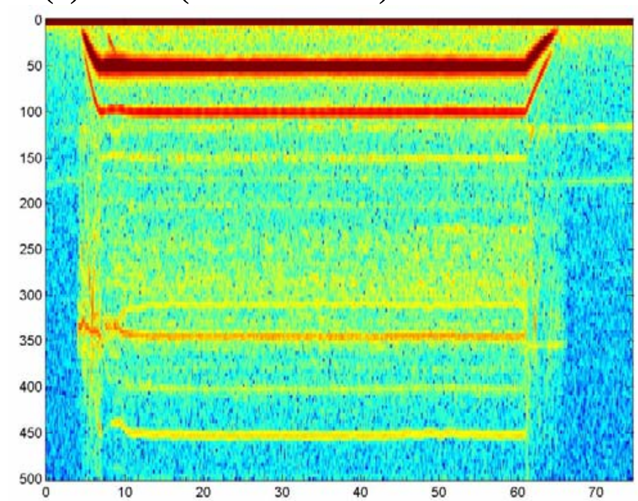
(a) Interstate I-35 2-inch (S3 – PG 64-22)



(b) 3-inch (S3 – PG 64-22) on 6 inch Concrete base

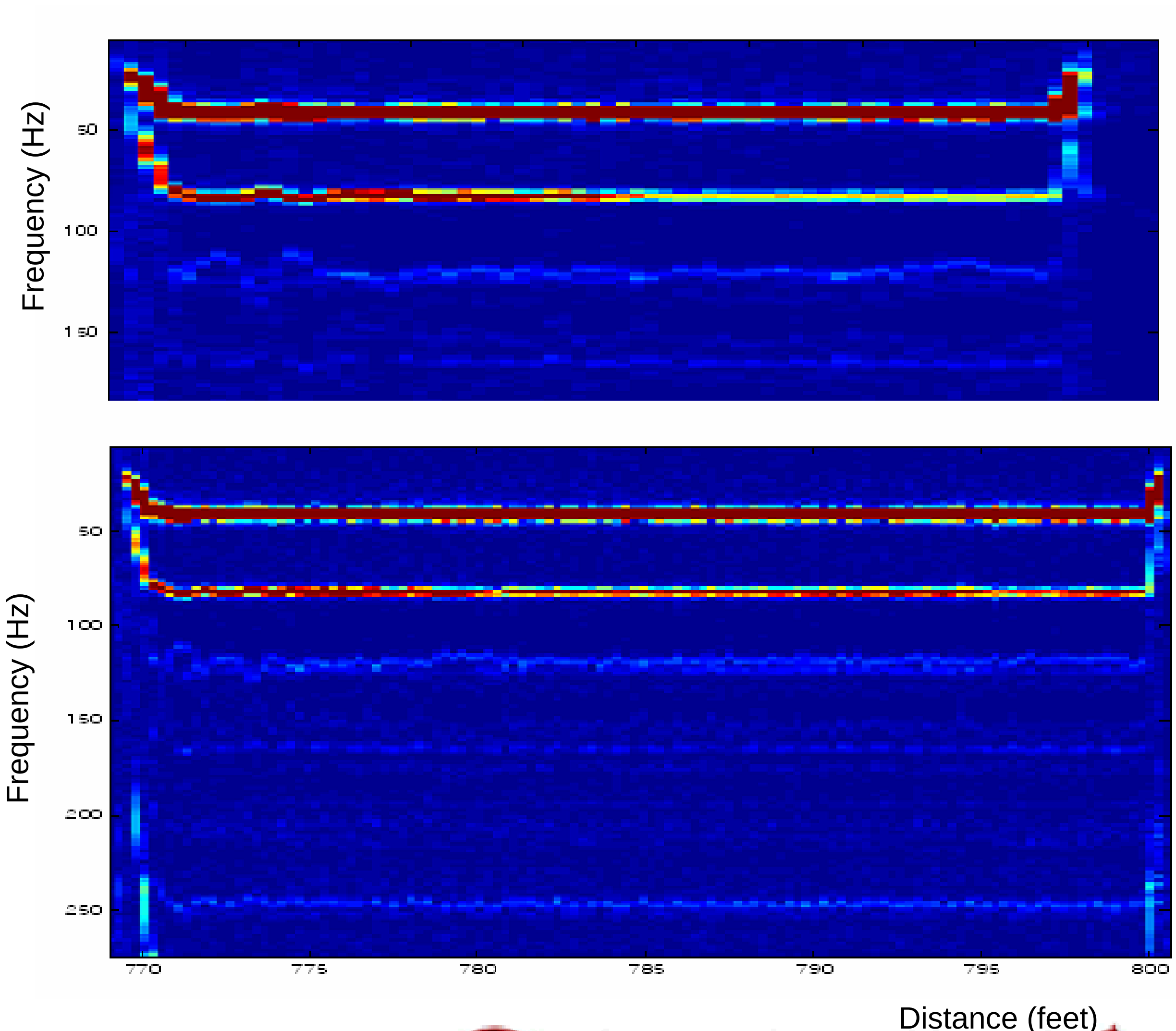


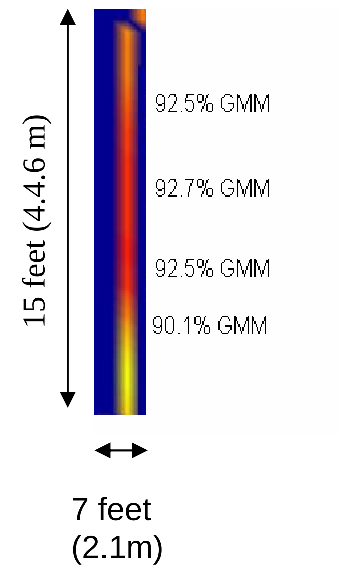
(c) 4-inch (S3 – PG 64-22) on compacted subgrade



(d) 2-inch (S4 – PG 70-28 OK) on 8 inch S3

Spectrogram Showing the Progress of Compaction During Two Successive Passes Over the Same Stretch of the Pavement.





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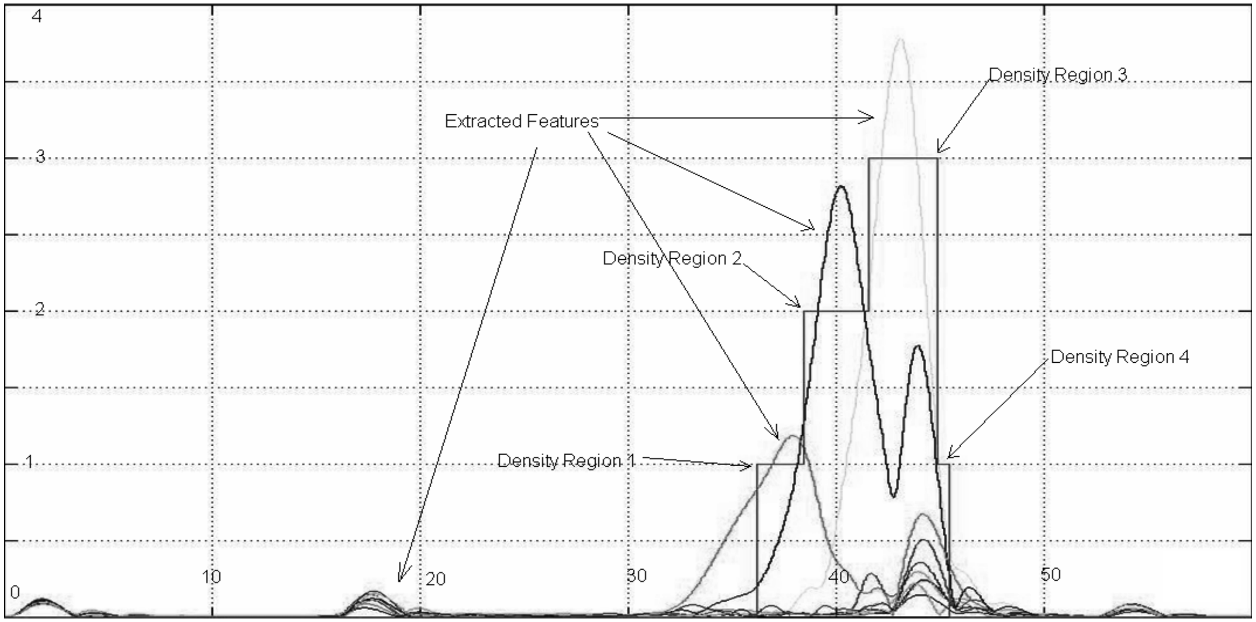
Laboratory Compaction of Asphalt Mix
To A Desired Density



Scale (X axis): 10 units = 25 seconds

S. No	Desired Density (%Gmm)	Achieved Density				
		Test 1	Test 2	Test 3	Test 4	Test 5
1	92.0	92.9	92.9	92.2	92.8	92.9
2	94.0	93.6	94.2	94.2	93.7	93.6

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Compaction Under Controlled Field Conditions

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Validation of IACA During Construction Under Controlled Test Conditions

Pass	Point	Left			Center			Right		
		Moisture (%)	Density (pcf)	Relative Density (%)	H20	Density (pcf)	Relative Density (%)	H20	Density (pcf)	Relative Density (%)
1	1	4.6	143.2	92.2				4	142.8	91.9
	2	5	144.1	92.8				4.6	143.6	92.5
	3	4.9	144	92.7						91.9
	4	4	142.5	91.8						
	5									
2	1	4.4	143.8	93.1				4.8	147.5	93.1
	2	4.9	144.8	93.4	4.8	144.4	93	4.7	144.9	93.4
	3	5	144.7	93.2	5	144.2	92.9	4.8	144.7	93.3
	4	4.8	144.3	93.3	5.4	145.3	93.6	4.8	145.1	93.5
	5	5.1	145.3	93.6	5.3	143.5	92.5	6.7	147	94.1
3	1	4.3	144.8	93.3	4.3	144.2	92.9			
	2	4.9	145.1	93.5	4.1	143.9	92.7			
	3	5	145.4	93.7	4.7	144.3	92.8			
	4	4.9	145.3	93.4	5.1	145.2	93.6			
	5	5.4	146.6	94.4	5.4	143.4	92.4			
4	1	3.9	143.6	92.5	3.5	142.9	92.1	4.2	145.8	93.5
	2	4.9	144.8	93.2	4.1	143.8	92.7	4.4	144.9	93.4
	3	4.7	145	93.1	4.6	145.4	93.4	4.2	144.5	93.1
	4	4.3	144.7	93.2	6.3	146.4	93.3	4.6	145.5	93.5
	5	4.9	144.5	93.1	5.3	144.1	93.8	7.7	145.6	94.1
5	1	4.4	144.6	92.9	3.4	143.1	92.1			
	2	5.1	145.7	92.8	4.1	144.1	92.9			
	3	4.6	142.8	93.1	4.9	146.3	94.2			
	4	4.4	144.8	93.3	4.5	145.3	93.1			
	5	5	145.8	92.1	5.6		93			

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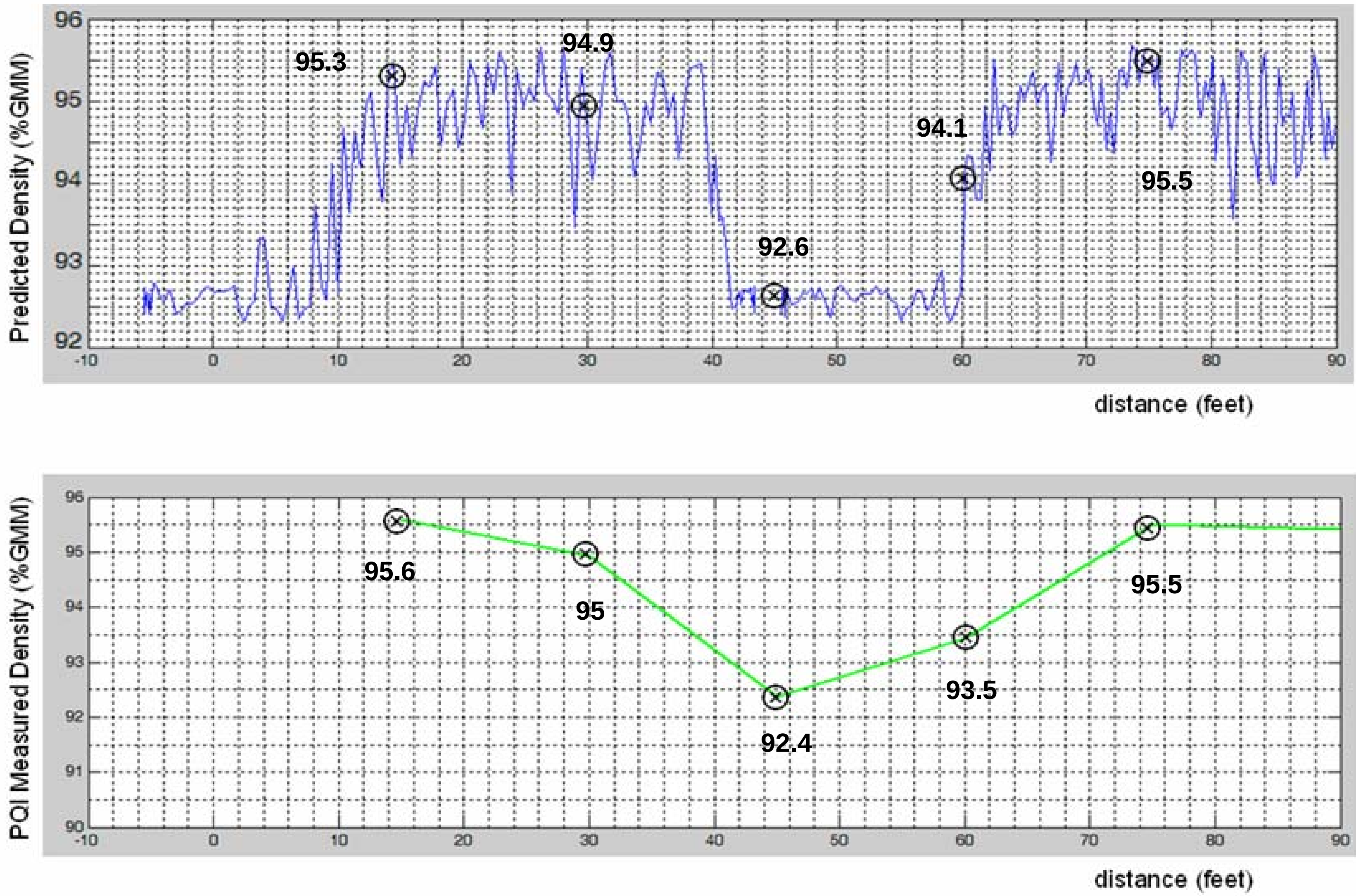
Comparison of IACA Predicted Density with PQI 301 Reading



Will Rogers International Airport
Construction July 20-28, 2006

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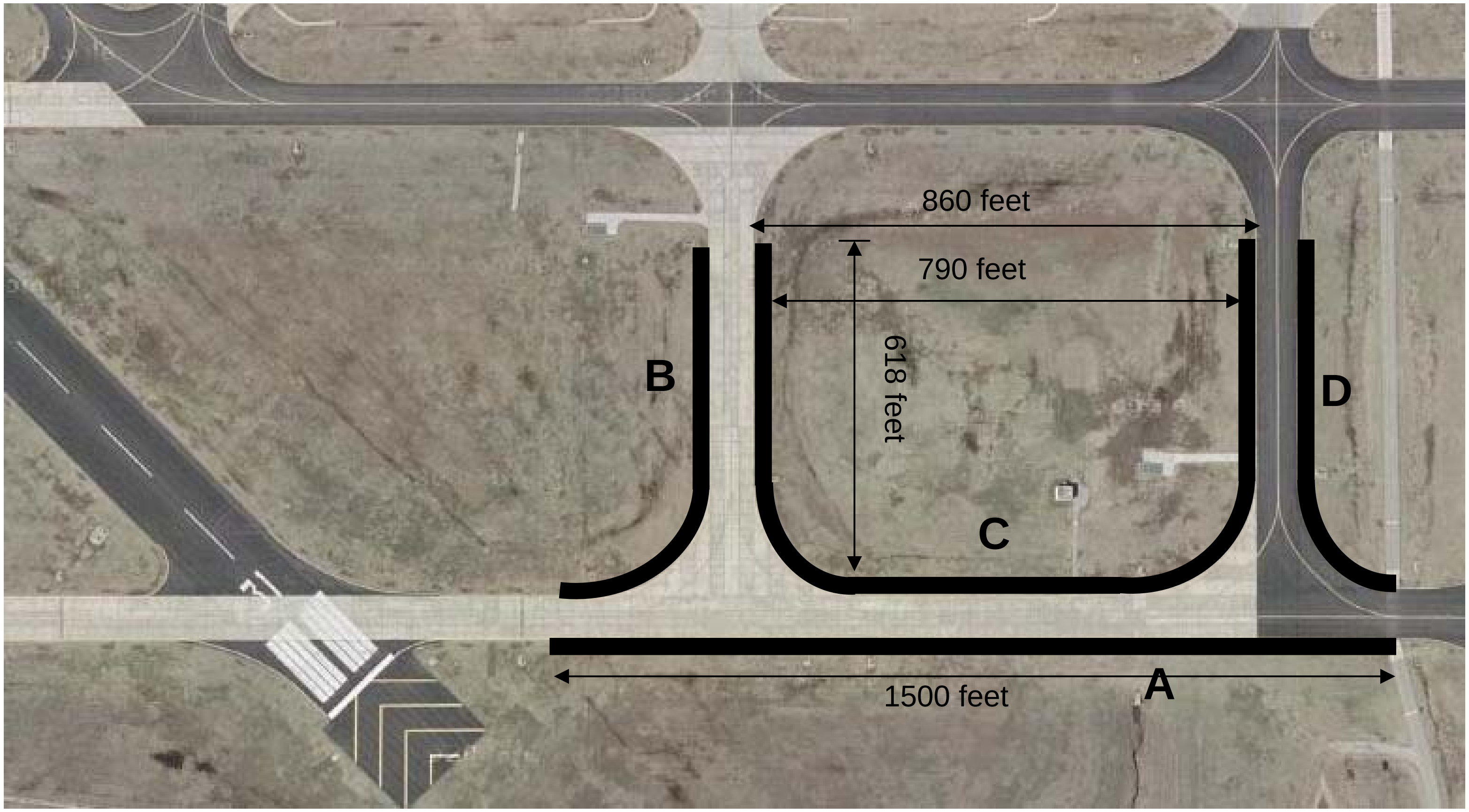

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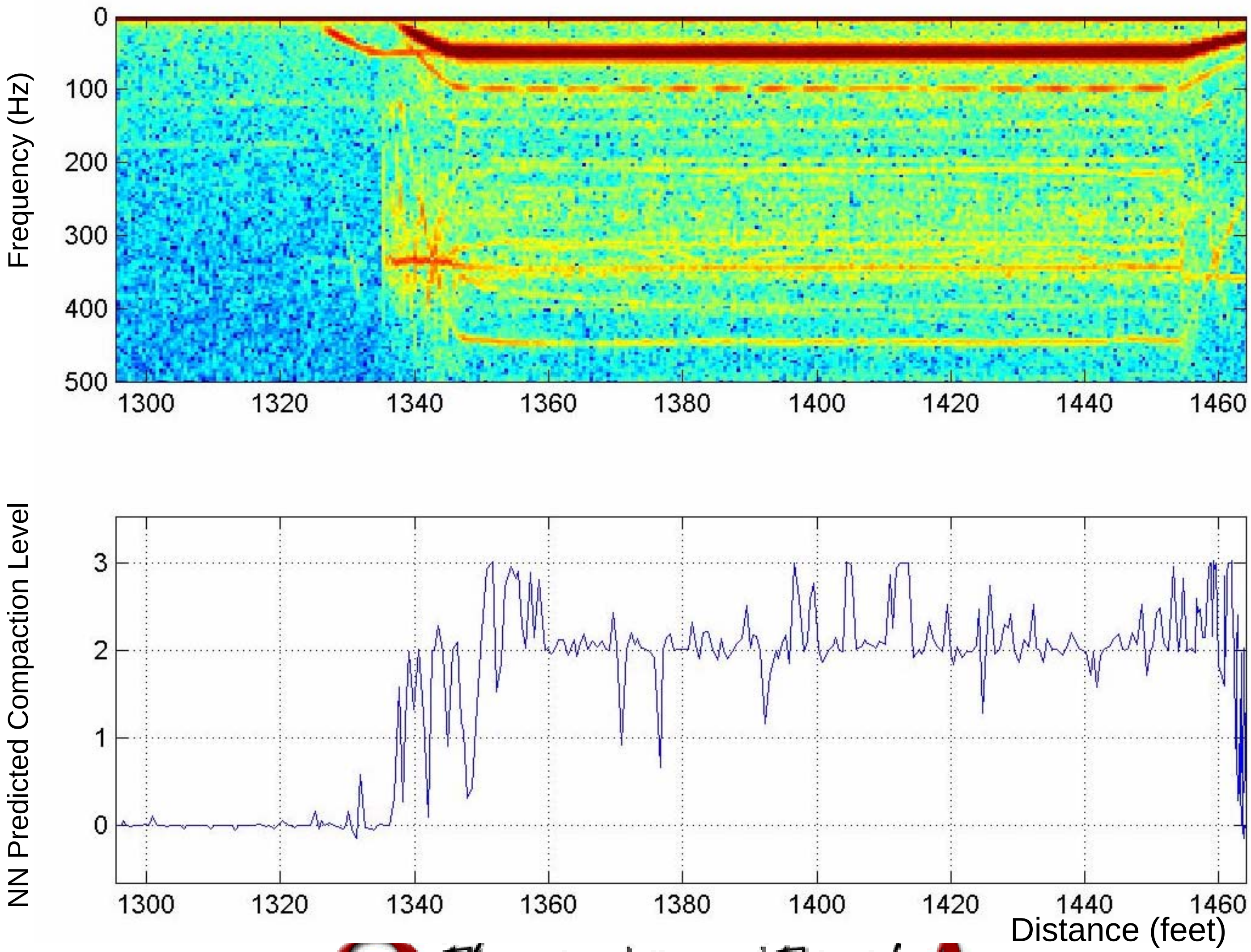
Spectrogram of Vibrations and Predicted Density – Pass 2



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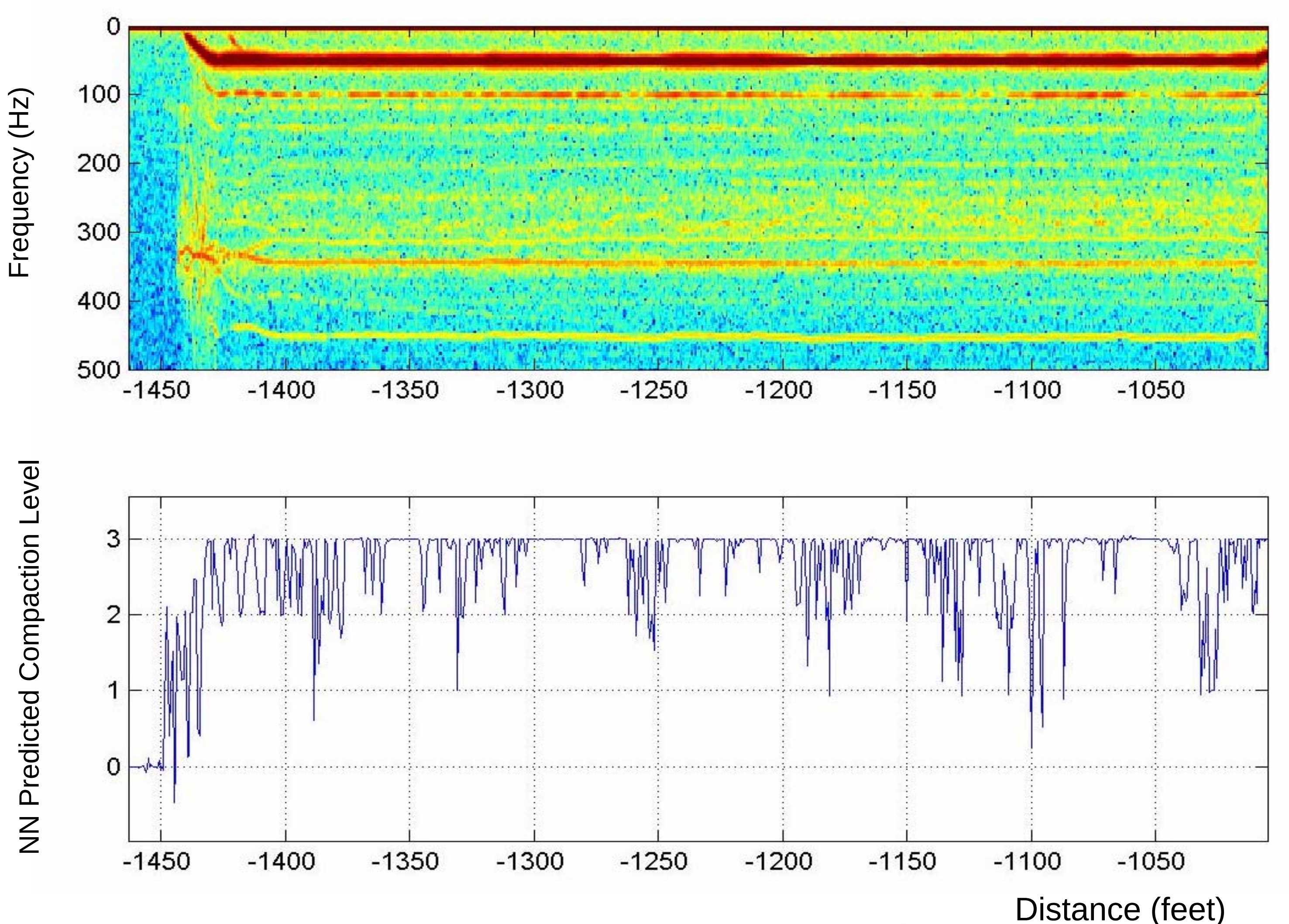
Spectrogram of Vibrations and Predicted Density - Pass 3



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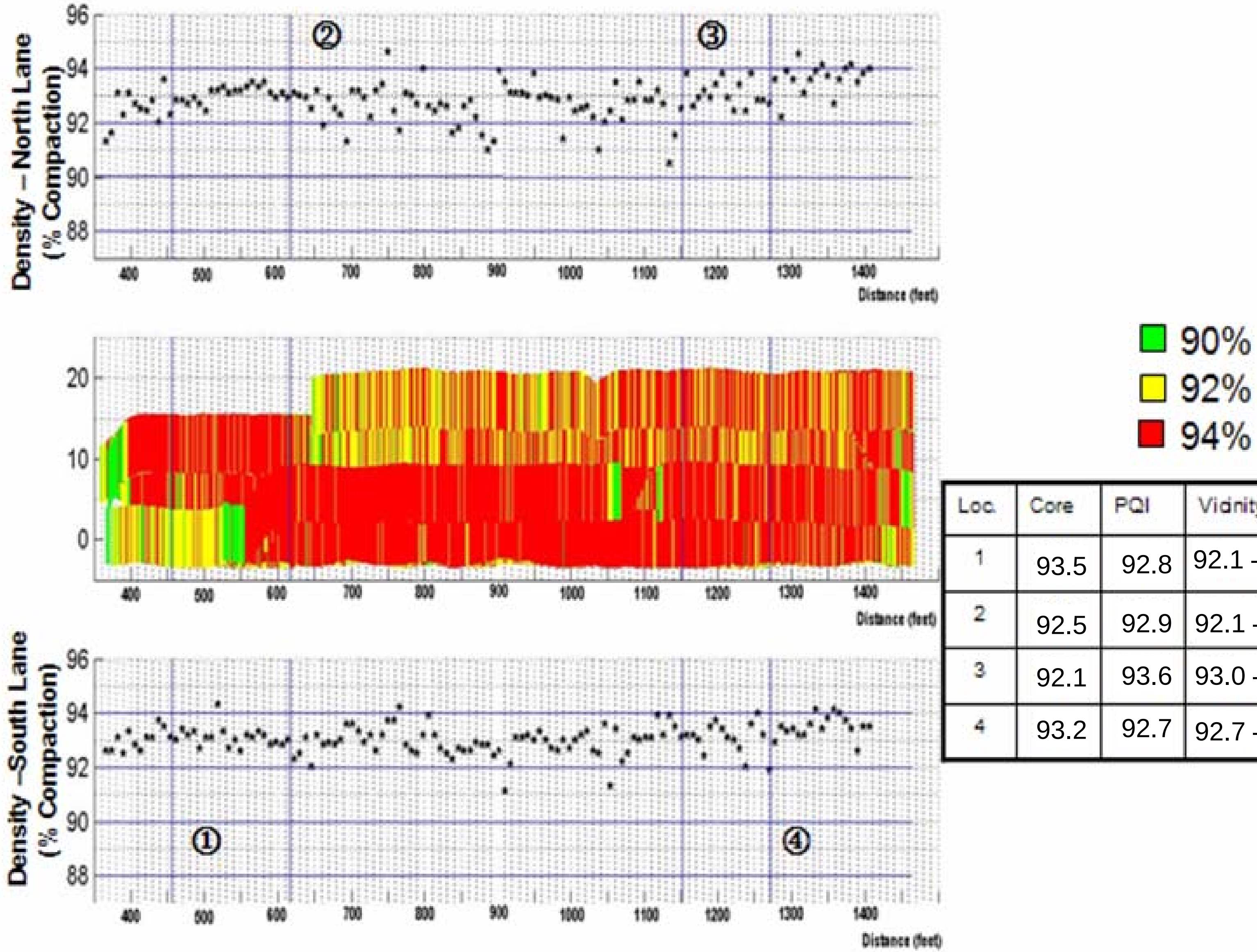
As Built Density Map with PQI readings and Roadway Core Densities



Loc.	Core	PQI	Vicinity
1	93.5	92.8	92.1 – 93.4
2	92.5	92.9	92.1 – 92.9
3	92.1	93.6	93.0 – 93.6
4	93.2	92.7	92.7 – 93.4

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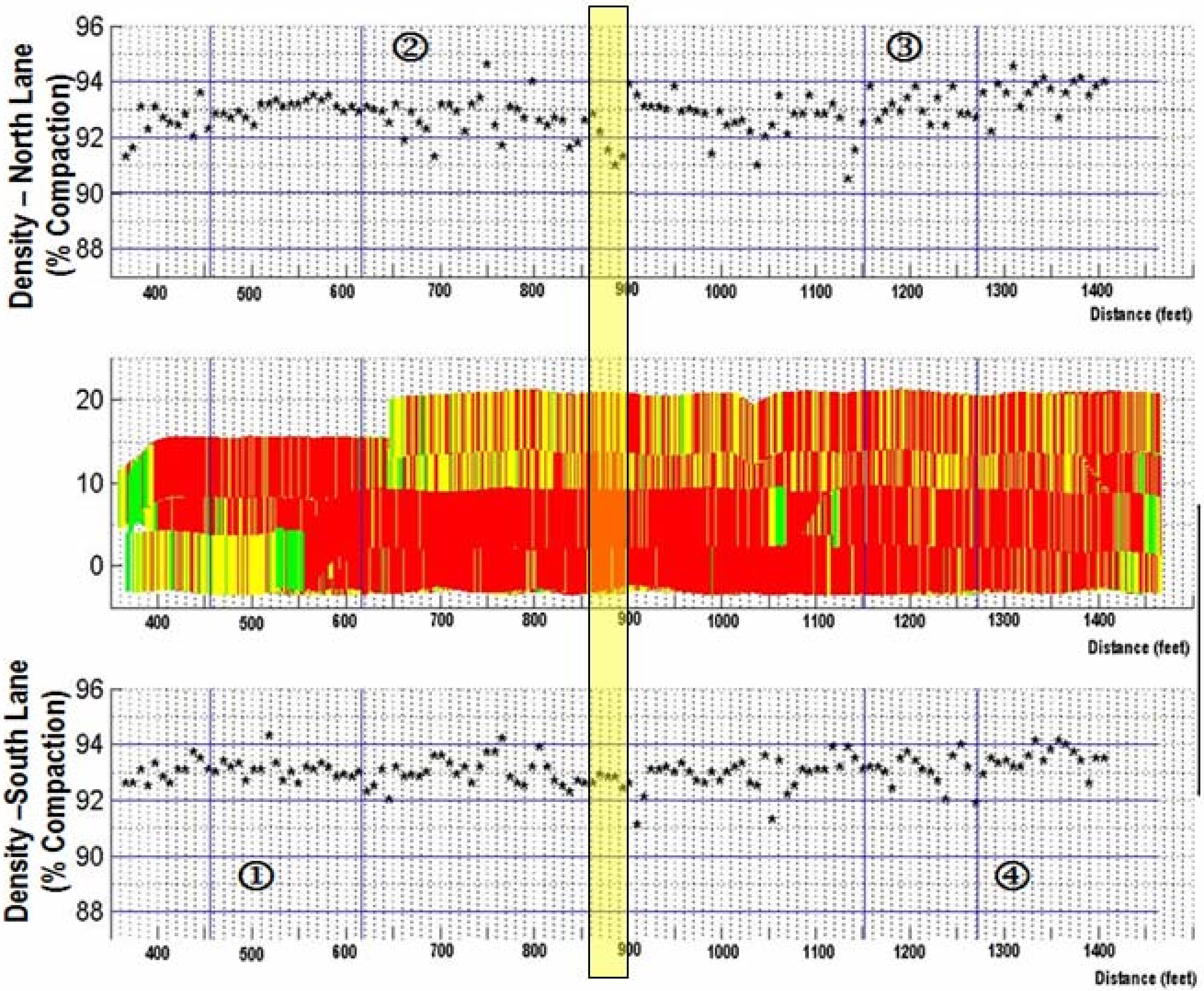
As Built Density Map



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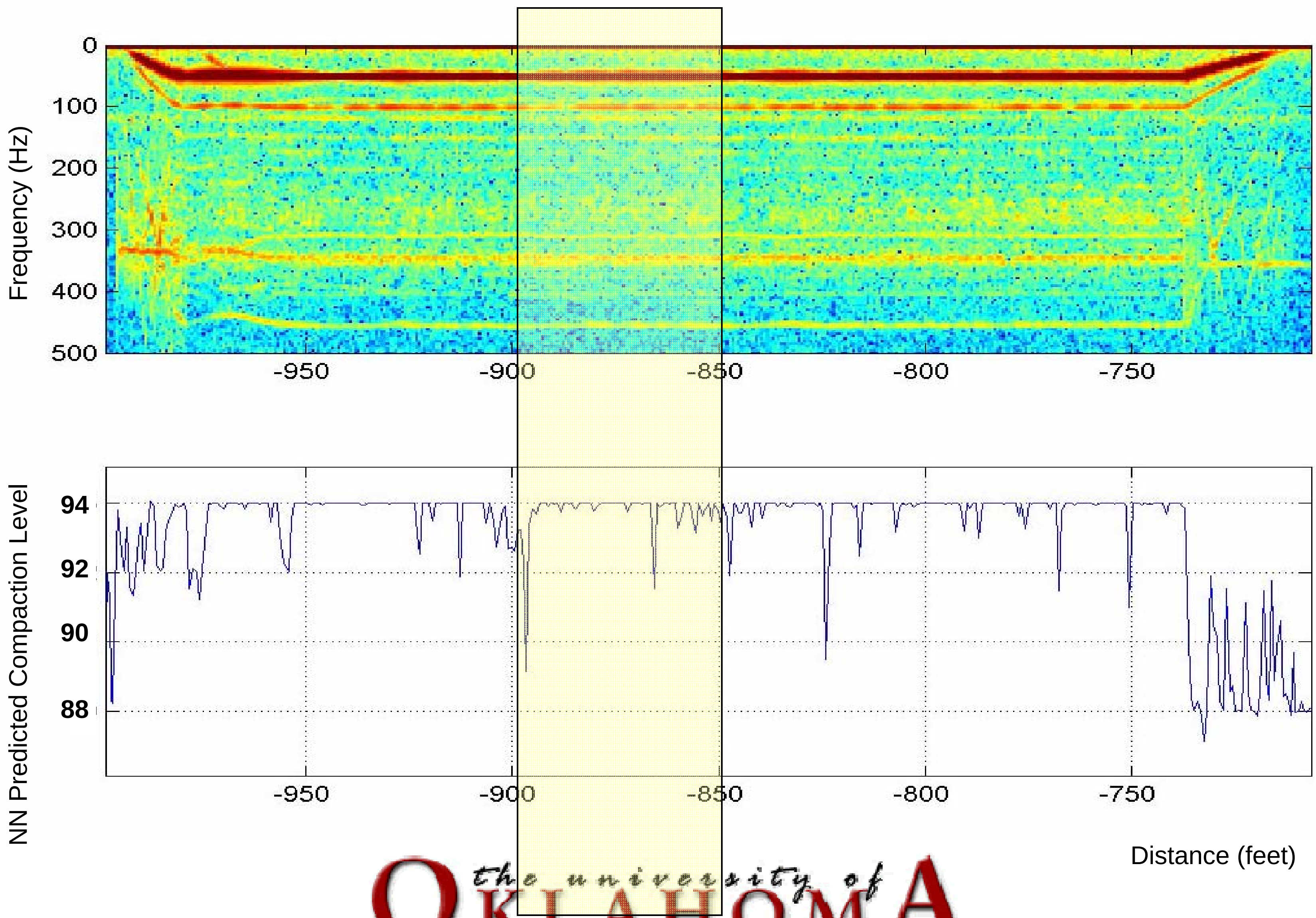
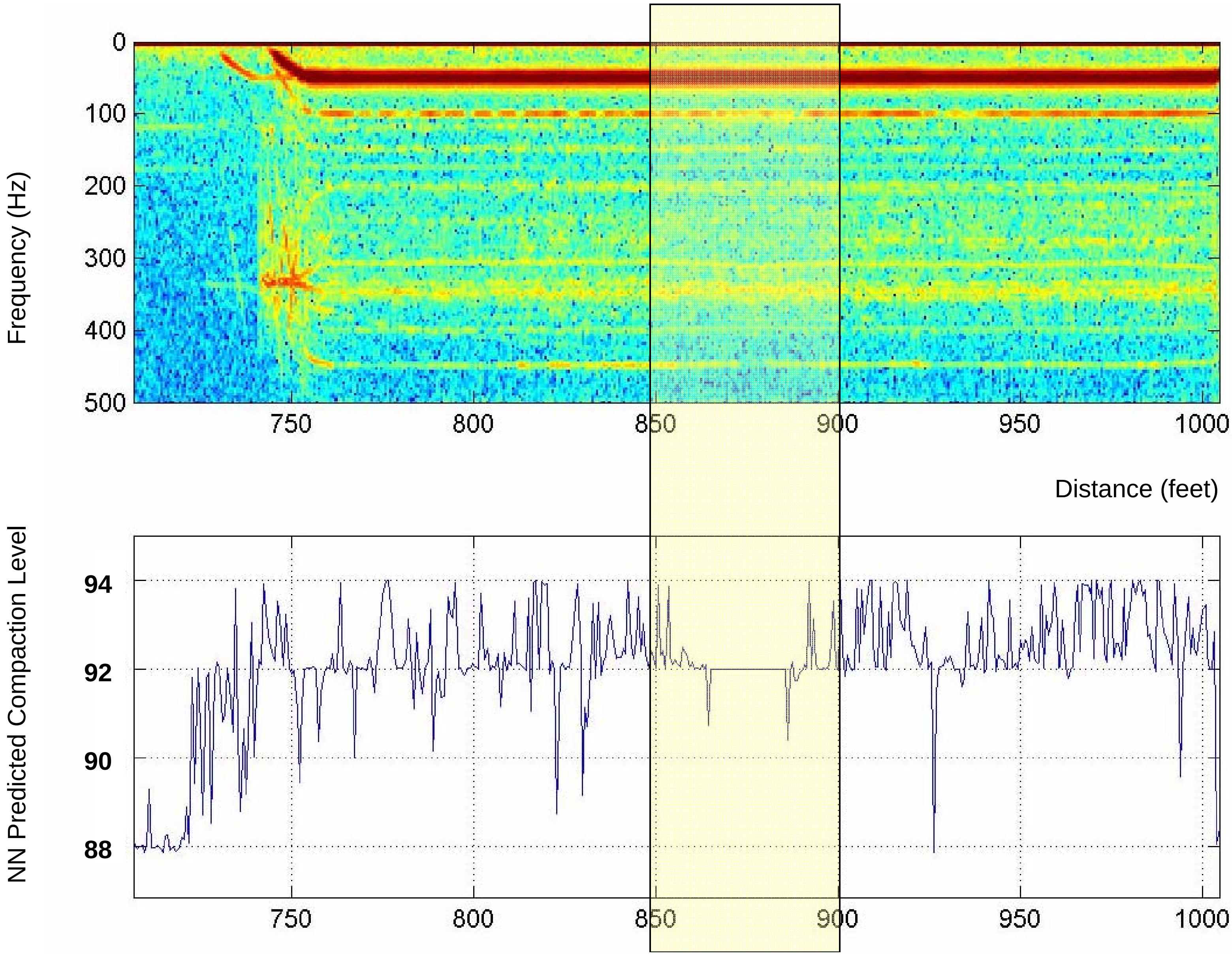
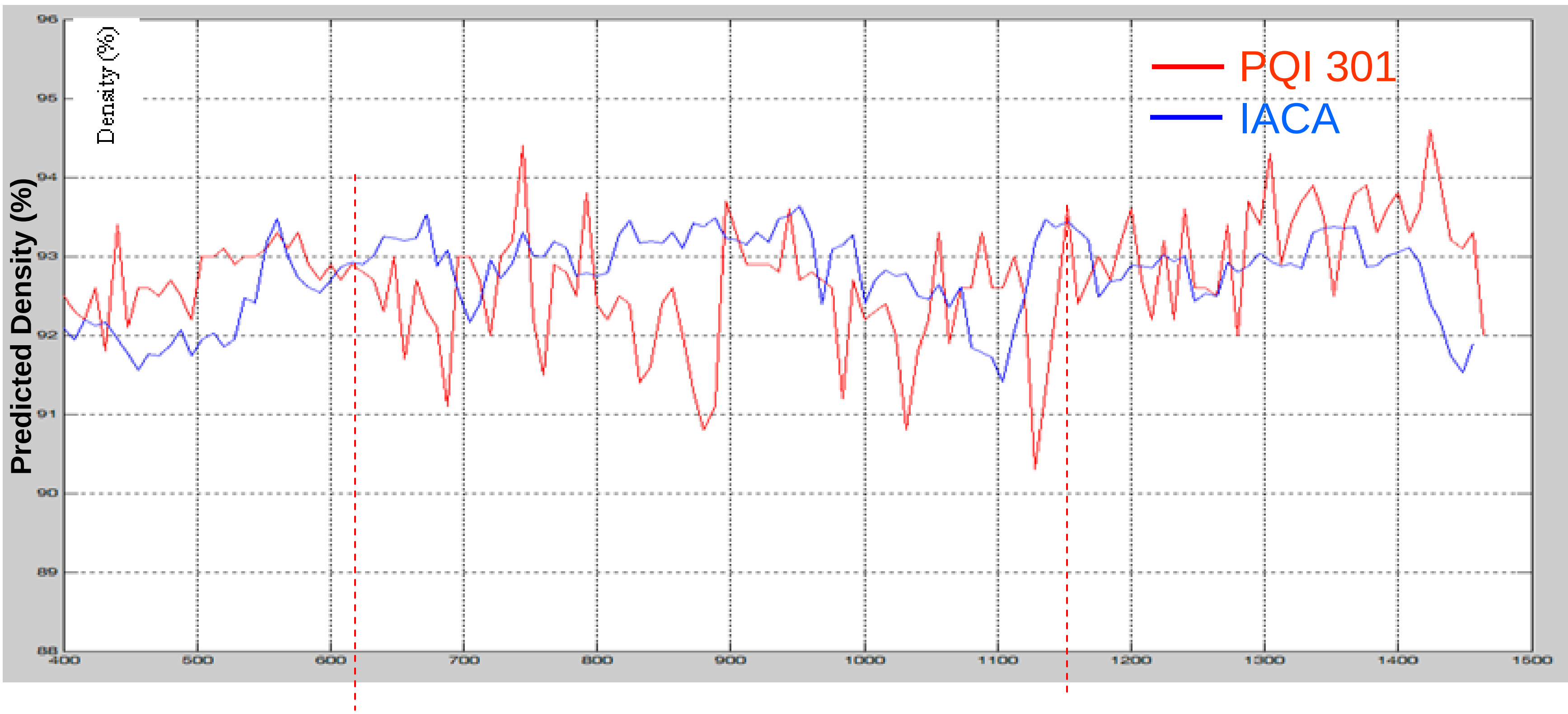
Final Pass - South Lane



Final Pass - North Lane



Density Measurements on the Compacted 3” Base Layer (North Lane)



Distance

Location 2
Core – 92.5
PQI – 92.9
IACA – 92.9

Location 3
Core – 92.1
PQI – 93.6
IACA – 93.4

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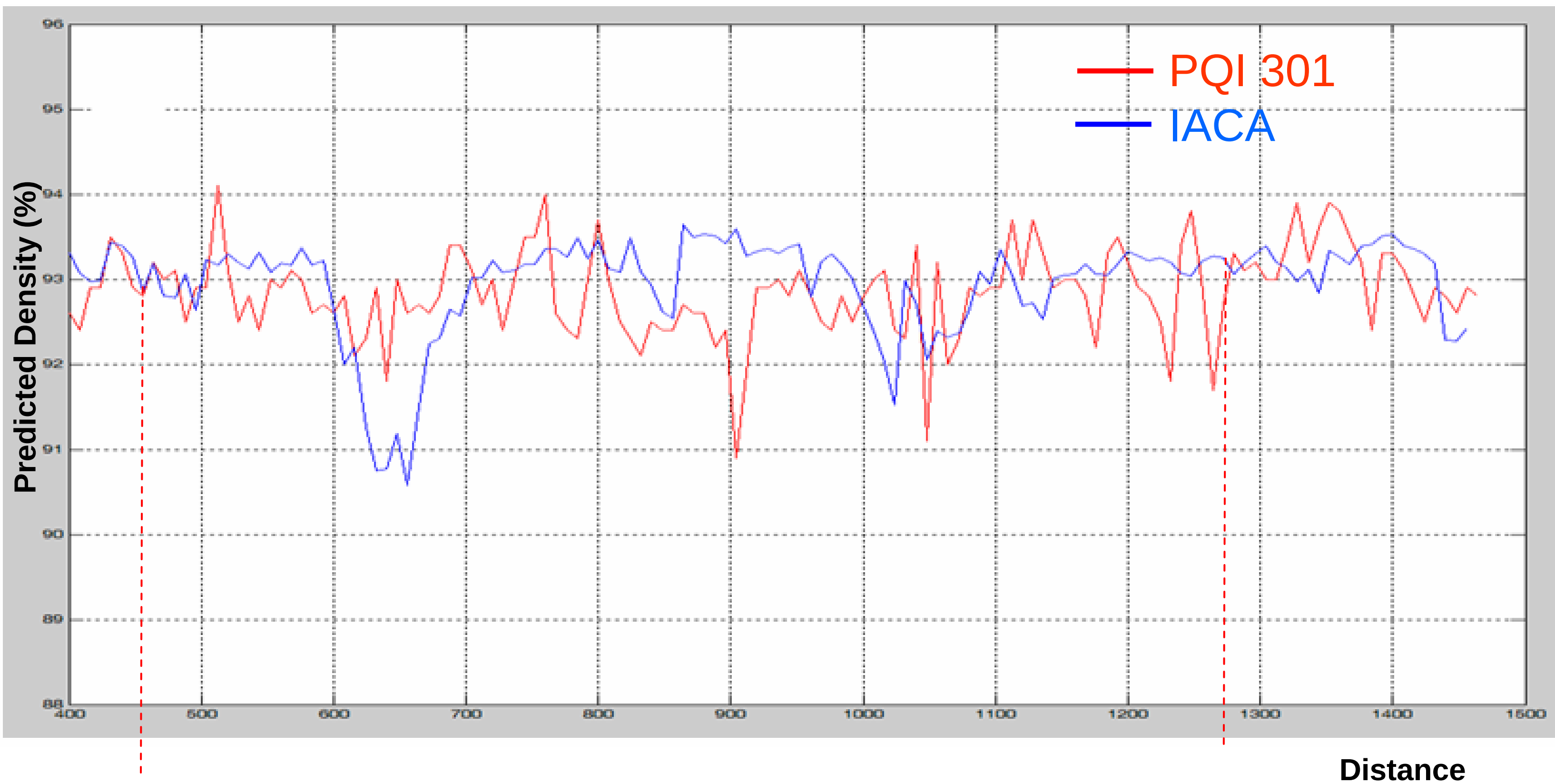
Density Measurements on the Compacted 3” Base Layer (South Lane)



Location 1
Core – 93.5
PQI – 92.8
IACA – 92.9

Location 4
Core – 93.2
PQI – 92.7
IACA – 93.2

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Comparison of Predicted and Measured Densities

S. No	Location (feet)	PQI Reading (%)		IACA (%)		Core Density (%)
		North Lane	South Lane	North Lane	South Lane	
1	456	92.6	92.8	91.6	92.9	93.5
		Range: 92.1 – 93.4		Range: 91.6 – 93.4		
2	616	92.9	92.1	92.9	92.2	92.5
		Range: 92.1 – 92.9		Range: 92.0 – 92.9		
3	1152	93.6	93	93.4	93.0	92.1
		Range: 92.8 – 93.6		Range: 93.0 – 93.4		
4	1272	93.4	92.7	92.9	93.2	93.2
		Range: 91.7 – 93.4		Range: 92.5 – 93.3		

Relief Features in Subgrade

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Future Work

- Automate the training process
- Port the application to a rugged, industrial ECM
- Develop customizable Graphical User Interface and report generation mechanism
- Develop Scalable Application
- Field Testing and Validation

Conclusions

- Intelligent compaction techniques provide continuous monitoring and control of compaction process.
- Provides instantaneous and complete evaluation of the pavement being compacted.
- The technology demonstrates the possibility of retrofitting existing rollers for real-time monitoring of compaction quality.
- Can be used to identify problems in the subgrade before they manifest themselves in the pavements.

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Acknowledgements

Ingersoll Rand Road Company, Shippensburg, PA.
Oklahoma Center for Advancement of Science and Technology (OCAST)
Broce Construction Company, Norman, OK.
Oklahoma Department of Transportation (ODOT)
Haskell Lemon Construction Company, Oklahoma City, OK.
Oklahoma Transportation Center (OTC)

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