ASPHALT PAVEMENT RADAR ANALYSIS

Innovator: Robert L. Lytton, PhD, PE

What the Innovation Is:

Dr. Lytton has developed a method for determining pavement layer composition through the analysis of radar signals. The new method is called Pavement Composition Analysis (PCA) and works as described below.

A four-antenna array of air-launched, ground penetrating radar (GPR) equipment is used to obtain digitized images of reflected radar signals from a multi-layered subsurface system. Standard mathematical techniques are applied to each trace to determine the number of layers, the thickness of each layer, and the dielectric constant, or specific electric property, for each layer within the multi-layered system. PCA takes advantage of the fact that each layer is composed of three distinct types of material: solids, fluids, and gases (air). Thus, the dielectric constant obtained for a layer is, in fact, a composite value, namely a combination of the layer's solid, fluid, and gas dielectric constants.

PCA employs a wave propagation model of the subsurface system to generate a synthetic reflected radar signal. Through an iterative process, initial concentration estimates of each material (solid, liquid, gas) in each layer are adjusted to minimize the mean-squared-error between the measured reflected and calculated synthetic radar signals. This process converges rapidly and yields accurate values for solid, fluid, and gas composition for each layer. The PCA software then plots lane-width maps showing contours of the composition elements such as unit weight, voids in the mineral aggregate (VMA), asphalt content, and air content. The PCA method can also be applied to concrete, aggregate, and soil layers.

Origination/History/Future of the Innovation:

Dr. Lytton began work on PCA in 1995 in Bryan, Texas. In the early part of this decade, Lyric Technologies used the PCA method for various pavement projects in Texas, New Mexico, and Florida. EPIC, Inc. (www.epicpavements.com), headquartered in Tomball TX, licensed exclusive rights to PCA in 2004 with the express purpose of expanding PCA's use in the paving industry. EPIC, Inc. currently has 5 regional offices servicing 16 states.

Why It Is Innovative:

PCA provides complete versus discrete testing. PCA is equivalent to analyzing 18,000 cores in a given lane-mile of a project while reducing time, cost, and the risk of injury/death to workers and motorists inherent to coring operations.

What It Changed or Replaced:

Other than the 2 cores required for calibration/verification every 4 lane-miles, PCA eliminates the need for coring.

Contact: Randall W. Brown, PhD, PE • EPIC, Inc • P.O. Box 168 • Tomball, TX 77377
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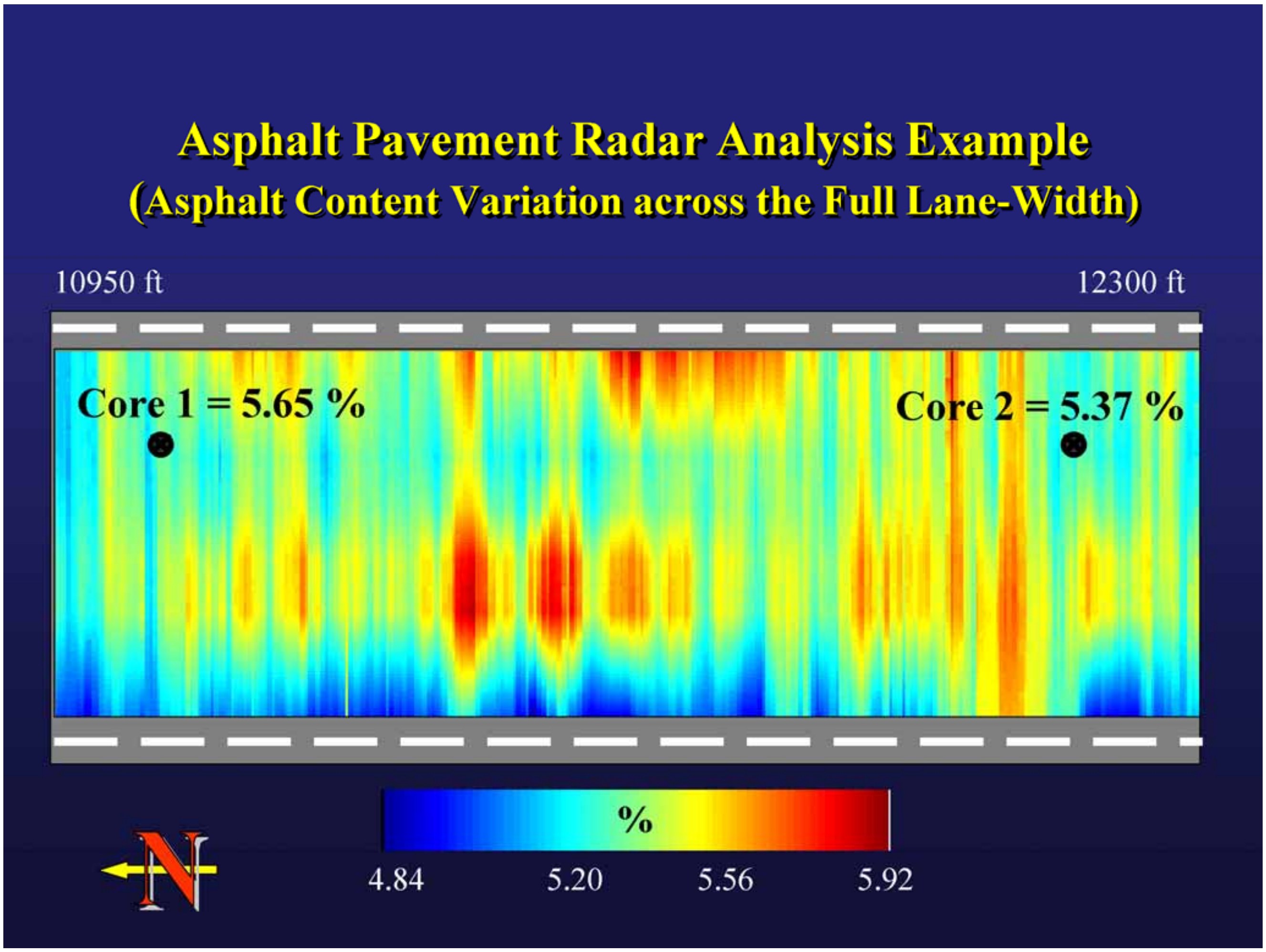
Asphalt Pavement Radar Analysis Example
(Asphalt Content Variation across the Full Lane-Width)
10950 ft
12300 ft
Core 1 = 5.65 %
Core 2 = 5.37 %
%
4.84
5.20
5.56
5.92
N

INVESTIGATOR'S SUMMARY[1]

Nomination 2006-23

Investigator: Vineet R. Kamat,[2] Ph.D.

ASPHALT PAVEMENT RADAR ANALYSIS

The Innovation

The use of Ground Penetrating Radar for quality assurance in pavement construction is based upon a combination of the physics of electromagnetic wave propagation in a dielectric medium and the discipline of micromechanics of composite materials. The two principles in wave propagation are that the speed of travel of an electromagnetic wave in a dielectric medium is inversely proportional to the square root of the relative dielectric constant of that medium and the rules governing the reflection and transmission of wave energy at an interface between two materials of different dielectric constants. The discipline of micromechanics of composite materials gives rules based upon the conservation of energy of how the dielectric constant of a composite depends upon the volumetric concentrations of the constituents of that composite. There are several applications of these principles that have proven to be useful to the construction industry and to the agencies that have the responsibility of assuring the quality of the construction. These applications are described below.

The equipment that collects the data consists of four radar antennas mounted abreast across a pavement lane which acquire an instantaneous radar cross section of the pavement lane every 1.7 feet of travel down the highway while traveling at highway speeds (see figure on following page). The precise location of the cross-section is an essential piece of information for quality assurance and this is determined by a sub-meter accuracy differential Global Positioning System (GPS) measurement that is made continuously with each run of the radar equipment down the road. As a back-up piece of information, a Distance Measuring Instrument (DMI) which is mounted on the rear axle is also run simultaneously. Both distance and location measuring readings are recorded on the same file in which the raw radar data from the four antennas are stored.

The central frequency of the antennas is 1 GigaHertz. This permits a depth of signal penetration that varies with how wet the pavement is but typically, 18 to 24 inches for asphalt pavements and 10 to 14 inches for concrete pavements. An extensive development of software was required to analyze the radar signals and display the products of the analysis graphically to provide the types of information that were found

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[1] September 21, 2006

[2] Assistant Professor, Civil & Environmental Engineering, University of Michigan, Ann Arbor, MI 48109.

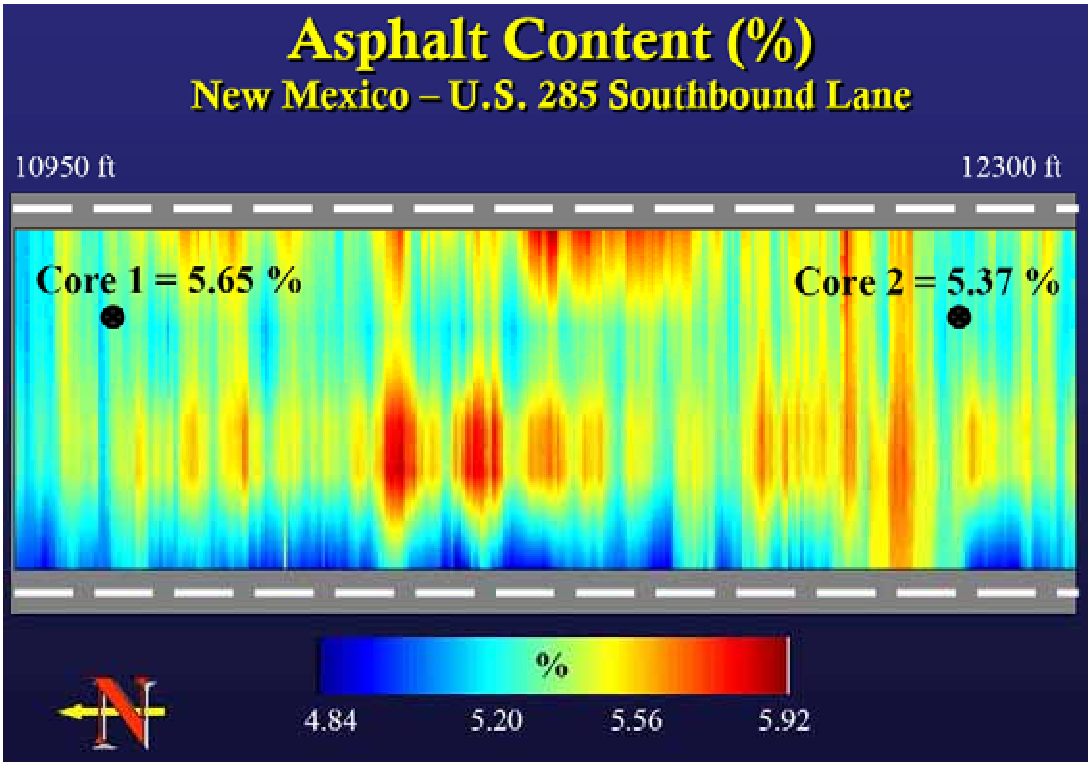
to be practical, useful and desirable by both contractors and highway agencies. Some of these graphical data displays can be produced in post-processing within ten minutes of the completion of any run of the equipment (see figure on following page). Others that show the normal quality control and quality assurance properties of a pavement layer require calibration to ground truth information that is obtained from cores that have been tested in a competent laboratory.

When such calibration is required by the need for accuracy, the turn-around time on the analysis is about one and a half days for about 5 to 10 miles of pavement, provided the laboratory can produce the lab test data within a half day of the cores being taken. As a quality-control measure on the analysis, one core is used for calibration and another is used for verification on each four-mile length of pavement. When such cores are required, it has been found that one core every four miles of a lane provides sufficient information for accurate composition analysis. The exception to this is that if the aggregate that is used in the mix changes, another core and calibration is required to achieve consistent accuracy. The same analysis and calibration technique has been used successfully on asphalt, concrete, base course, and subgrade layers of pavements.

The applications that have been developed for the use of the radar signal analysis can be divided into those that require calibration and those that do not. As contractors and highway agencies gain confidence in these methods, new capabilities are developed. The present capabilities of the software to analyze and display graphically include:

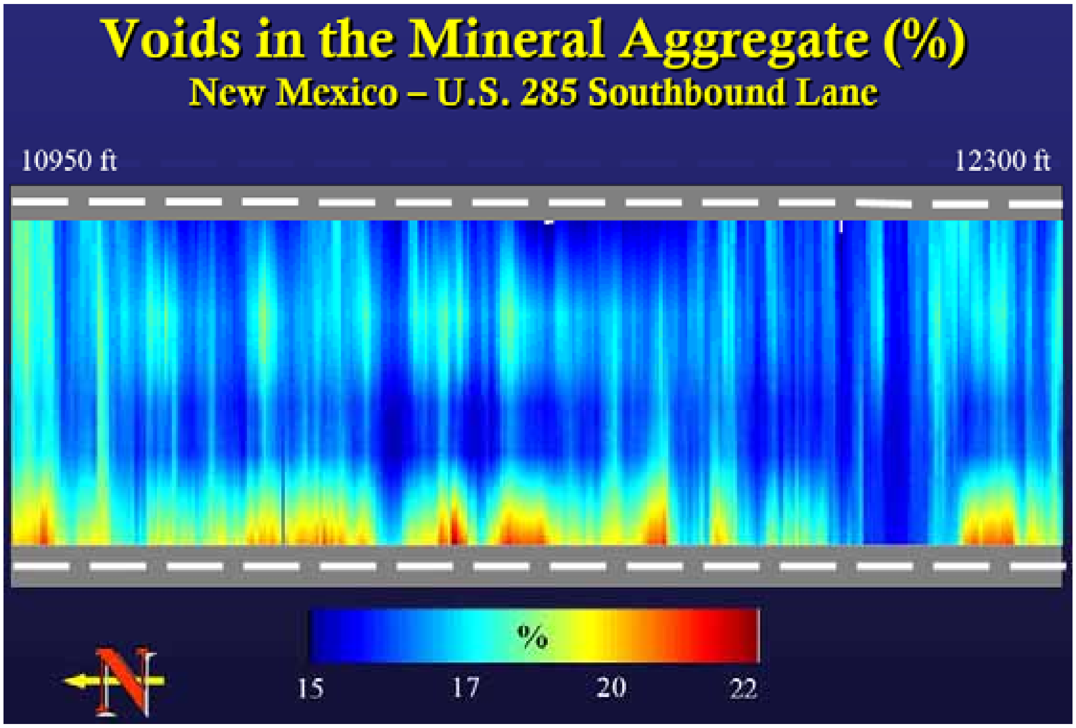
<u>**PCA**</u>: Pavement Composition Analysis which determines the volumetric concentration of solids, liquids and air in the mixture. This has been applied successfully to asphalt, concrete, base course and subgrade layers. In asphalt, the liquid is the asphalt content. In concrete, the liquid is the evaporable water content. In base course and subgrade layers,

the liquid is the water content. In asphalt layers, PCA calculates and displays graphically the density, asphalt content, percent air, and the voids in the mineral aggregate. In concrete layers, PCA calculates and displays the density, evaporable water content, porosity and percent air.



PVA: Pavement Voids Analysis which can usually be provided in post-processing analysis except in cases where the layer thickness or moisture varies considerably over the length of the pavement run that has been made. This application searches for the radar signature of a void between the bottom of the top layer and the top of the base course layer beneath it and determines the thickness of the void. The software produces a map of the location and the thickness contours of each void that is found. The accuracy of this method of has been verified by a double blind study conducted in 2004 and reported by Applied Research Associates (ARA) with headquarters in Champaign, Illinois. The software computes the volume of individual voids and the sum of the volumes of voids in the entire project. This is used, particularly in concrete pavements, to find where underseals need to be placed to restore support of the surface layer. This is useful at joints where pumping and erosion have reduced load transfer across the joint or crack.

PTA: Pavement Thickness Analysis which has been done with radar for years but this application is unique in that it produces a color contour map of the thickness of the pavement across the full lane width and the length of the run. Greater accuracy can be achieved if a core is used to check on the ground truth of the actual pavement layer thickness. Inaccuracies develop because of moisture in the pavement and changes in layer composition from point to point.



RCP: Relative Compaction Profile is an analysis that can be produced in post-processing within ten minutes of the completion of the run. The software plots color contours of the relative density of the pavement surface layer. Contractors and highway agencies have found that this color profile of approximate density gives the location where the highest and lowest and intermediate densities are to be found and provides information on where to take cores to see if the section just scanned meets compaction specifications. This cuts down dramatically on the number of cores that must be taken for quality assurance and efficiently reduces the turn-around time required to identify any areas where the layer has been inadequately compacted. If pay quantities or penalty or incentive pay is involved, the accurate PCA analysis can be made subsequently using the few cores that are taken for calibration and verification.

Permeability: This analysis must be preceded by a PCA analysis and several field or laboratory measurements on cores of the permeability of the pavement layer. There is more variability in the permeability in the field than in the composition quantities and this requires a minimum of five measurements of permeability at locations where the composition of the material can be determined. The advantage of this is that at the end of this process, a lane-width, project length color contour map of the permeability can be displayed graphically. Areas with excessive permeability which will permit water to percolate into the layer and cause moisture damage or areas of low permeability which will not permit fog seals or surface rejuvenator agents to percolate into the layer can be easily identified.

Uniformity Index: This is a map that can be produced in post-processing showing where moisture damage (stripping) has occurred. It is based upon the observed fact that moisture damage proceeds in stages. In the first stage, moisture enters and raises the dielectric constant of the layer. In the second stage, the moisture displaces the asphalt from its adherence to the aggregate surface and traffic stresses erode the asphalt out of the layer, lowering the dielectric constant of the layer. In the final stage, the asphalt is gone and the moisture evaporates, and the dielectric constant of the layer reaches a minimum well below its as-constructed value. Thus, areas that have entered the first, second and final stages can be identified in a color contour map of the lane width and project length.

Pothole Potential: This is an empirical technique that was developed to assist cities and counties to locate areas where potholes are developing beneath the surface layers of the pavements within their jurisdiction. It works best when the surface layer is composed of a surface treatment, rather than a hot mix asphalt layer. There are other specialized uses of this technology that have been developed for specific applications and there are others that are anticipated for development for the near future. The applications described above give a good idea of the ways in which the radar analysis of radar signals has been used to increase the efficiency and timeliness and reduce the costs of the quality control/ quality assurance function of pavement construction.

Innovativeness of the Technology

The technology is innovative in several areas, namely (1) the theoretical combination of physics and micromechanics; (2) the use of four antennas abreast which makes it possible to map the entire lane width of the products of the analysis of the radar signals; (3) the software which is necessarily extensive to handle both the signal analysis and the graphical presentation of maps of the analytical results; (4) a detail which is not known to have been accomplished elsewhere and that is to shield the GPS signal from the GPR signals and to prevent them from interfering with one another.

Application of the Innovation

The benefits of applying this technology to construction quality assurance/quality control is both in reducing costs and greatly reducing turn-around time for the QA/AC test results. Realistic estimates of the reduction in costs show that the previous cost of taking cores at random and running the tests on them all as compared with this much more sparse requirement for cores and providing a PCA map of the result is that the cost has been reduced to half of what it was before and the time required has been reduced from the usual several months to several days.

Adding the feature of RCP has greatly enhanced the ability to take cores where the information they provide is more useful than a set of random cores. In those cases where the compaction has been within specifications, the full lane width, full project length map of the actual compaction as placed has greatly accelerated the approval and authorization of payment processes.

Background of the Innovation

The original idea for the use of radar for construction QA/QC applications was originated in 1991 by Dr. Robert L. Lytton during the Strategic Highway Research Program (SHRP). The idea was fully developed to the point of receiving a U.S. Patent on January 24, 1995. Lyric Technologies, Inc. was formed to develop the patent idea into practical applications. In addition to the present applications, the use of radar to detect delaminations in pavements and bridge decks and the presence of Alkali-Silica Reactions (ASR) in concrete pavements such as are being found to provide Foreign Object Damage potential in airport pavements are expected future uses in pavement applications. Other areas where these may find useful applications are in the area of railroad ballast fouling and predicting the roll component on curves due to moisture softening of the subgrade. Other areas include the detection of non-metallic antipersonnel and anti-tank mines.

Responsibility for the Innovation

The idea of combining the physics of electromagnetic wave propagation with the discipline of micromechanics originated with Dr. Robert L. Lytton. He derived all of the equations and worked with the programmer, Arvind Devadas, to make the analytical system work. Many people are responsible for making this into a practical system. Chief among them is the principal supporter of the analytical and equipment development work, Mr. Brent Barron, and the President of Lyric Technologies, Mr. James A. Poston.

Design and construction of the antennas and transmission/receiving hardware was accomplished by Dr. Rob Peterson, PE. Development of the software (both analytical and graphical) and the custom Data Acquisition hardware was done by Arvind Devadas. Instrumental in solving initial problems in the analysis were two early employees of Lyric Technologies, Abigail Wells Alford and Cristina Marisa Cuellar Pena.

Finally, the person who actually got several agencies and contractors to use the technology was the President of EPIC (Electronic Pavement and Infrastructure Charting, Inc.), Dr. Randall W. Brown, PE.

Opinions of Persons Contacted

A list of people interviewed, along with a short summary, is provided ahead in this report in the section titled "Selected Interview Summaries". All the persons that I was able to establish contact with for information had positive remarks about the innovation and were enthusiastic in providing information on how the innovation improved their operations.

Investigator's Comments

The conventional system that is currently in use is taking cores on a random basis or in measuring the density and asphalt content using nuclear moisture-density equipment in the field to ascertain whether compaction specifications have been met.

The cost of the new system using radar-signal analysis and providing PCA maps is about half of the current methods. The time is reduced from several months turnaround to several days. Safety is no different in new construction. However, in determining the composition of existing pavements under traffic, the safety of collecting data from a van traveling at highway speeds is much greater than exposing coring or nuclear testing personnel to traffic in barricaded work zones.

There are no other competing methods that give the same information with the same quality. This technology has demonstrated capability to streamline construction QA/QC processes, while reducing costs and turnaround time and providing much more extensive and detailed information on the quality of construction. It also provides information to document the quality of construction so that contractors can provide detailed, objective data to bonding companies.

SELECTED INTERVIEW SUMMARIES

Randall W. Brown, PhD, PE
President – EPIC Inc.
P.O. Box 168
Tomball, TX 77377
Interview by Vineet R. Kamat, August 22, 2006.

Mr. Randall Brown was the primary contact person that this investigator communicated with for information on this innovation. Mr. Brown was very forthcoming and helpful in providing information for this investigation. Most of Mr. Brown's comments helped the investigator understand the innovation. Information from these comments has already been included in the earlier sections of this report.

Michael I. Hammons, PhD, PE
Principal Engineer
Applied Research Associates, Inc.
5000 NW 27th Court, Suite E
Gainesville, Florida 32606-6500
Interview by Vineet R. Kamat, September 15, 2006.

Dr. Michael Hammons is a consultant to the Florida department of transportation. He explained that his firm has been using the asphalt pavement radar analysis technique to get the relative compaction profile of pavements. In particular, Dr. Hammons explained that the radar analysis technique is being used by his firm to determine where the minimum and maximum densities occur in the pavement being inspected so that core locations can be selected in a manner that is not completely random. He mentioned that the technique is about 80% accurate in determining the minimum and maximum density locations. He explained that it was somewhat hard to say what the exact cost savings realized from the radar analysis technique were but said that they realize about 40% cost savings over the traditional method using this new technique. He also explained that some of these savings are offset by the cost of the radar equipment itself. But he was emphatic in saying that the accuracy and the cost savings realized are worth the additional cost of the equipment.

SUPPORTING EXHIBITS

1. **Technology Comparison Charts**
2. **ENR Article: Pavement Professor Breaks New Ground in Quality Control 10/24/2005**
3. **Lyric Self-Guided Technology Briefing**

Pavement Composition Analysis

Coring/Laboratory Analysis	EPIC Hyper Optic Solution
• Extraction of Dozens of Cores (Exact Number Depends on The Governing Agency)	• Extraction of a Calibration Core and a Verification Core Every 4 miles
• Extensive Disruption to Traffic Flow	• Limited Disruption to Traffic Flow
• Discrete Sampling (Pavement Characterized By Cores Taken at Random Locations)	• Complete Sampling (Pavement Characterized By Analyzing Hyper Optics Signals Throughout The Pavement System)
• Considerable Laboratory Expense	• Minimal Laboratory Expense
• Slow Data Turnaround Time	• Rapid Data Turnaround Time
• Data Presentation – Laboratory Reports	• Data Presentation •– Color – Coded Map of Each Element of The Pavement Composition and Layer Thickness • - On – Screen, Continuous GPS Coordinates and Micro – Odometer Distance Measurements

Pavement Voids Analysis

Conventional GPR	EPIC Hyper Optics Solution
• Single Antenna with Limited Coverage Area (~ 3' x 2')	• Multiple Antennae with Full – Lane width coverage (~ 12' x 2')
• Ground – Coupled Antenna	• Air-Launched Antennae
• Data Acquisition at "Crawl" speeds	• Data Acquisition at Highway Speeds
• Subjective Interpretation of Signals	• Mathematical Analysis of Signals
• Two – Dimensional Presentation of Data	• Three – Dimensional Presentation of Data

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equipment tracks & trends

Pavement Professor Breaks New Ground in Quality Control 10/24/2005

By Tudor Hampton

For years, construction engineers have used ground-penetrating radar to locate unseen materials. But one scientist is trying to use the same technology to scan the molecular makeup of those materials.

Discreet. *The EPIC truck may look like a family camper, but it is stuffed with an array of ground-penetrating radar equipment.*

The new radar method has the attention of some pavement engineers who are on the hunt for more accurate, non-destructive test methods. The technique has the potential to save owners "a lot of money," according to Michael Lithman, vice president of Ellis & Associates Inc.

The Jacksonville, Fla.-based engineering firm has hired Electronic Pavement and Infrastructure Charting Inc. (EPIC), Tomball, Texas, to handle scans for recent quality-control projects and was pleased with the results. "You can get rid of most of the cores on the job," Lithman says.

Florida Dept. of Transportation is experimenting with EPIC's radar system in order to check the compaction of asphalt pavement during construction, says Tim Ruelke, an FDOT district engineer. He is cautiously interested, saying, "We're not ready to go out into the rest of the state." But he says FDOT is "very intrigued."

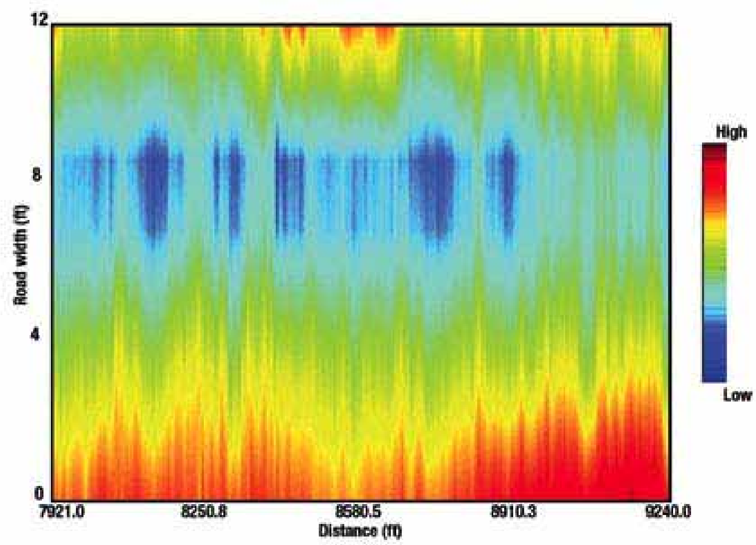
So are others. The National Center for Asphalt Technology in Auburn, Ala., began testing the new scanning service in late October, with a full report expected in six to nine months.

Formerly a unit of Uretek USA Inc., a pavement rehabili-tation contractor, EPIC spun off as a separate company last year. Its proprietary radar scan is the "next generation" of material testing, says Randall W. Brown, a retired Air Force engineer and president of EPIC.

Lytton

The inventor, Robert L. Lytton, is a civil engineering professor at Texas A&M University. He wrote the original logic that became the backbone of the new process. Unlike traditional radar, which detects the location of materials, EPIC uses an antenna array linked to a custom software program that parses a material's properties. It works for asphalt, concrete, aggregate and soils, the company claims.

"It never occurred to anyone to try to determine the composition of the layers," says Lytton, who in 1995 helped Texas A&M receive a patent for the technique. EPIC owns an exclusive license to use the technology. Lytton is a founding owner.



Hot Spots. *Patented radar technique reveals pavement composition, including relative compaction.*

The 68-year-old inventor conceived the idea in 1991. Lytton says he had been researching the mechanical properties of materials "for some time [but] never thought of applying the same discipline to the analysis of radar signals." To do that, "I had to get outside the field of radar and go into micromechanics," he explains. The research took Lytton into the study of light waves and the speed at which light travels through materials. By focusing radar signals into pavements, he not only could detect their thickness, but also the electromagnetic signatures of the materials inside. A special software program then could sort out the data and show a pavement technician the results in minutes. "I didn't run down the hallway yelling 'Eureka,' but I felt like it," he says.

EPIC performs such scans with radar antennas mounted on the rear of a large truck. It takes a reading up to 12 ft wide and 18 in. deep by simply driving down the road. It costs up to $9,000 for the first day and $4,000 for each additional day. Taking random core samples can cost about $50 per core but that method has other "hidden" costs, engineers say. These include shutting down lanes and not knowing where to drill in the first place. The new method still requires some initial cores for calibration.

Ultimately, Lytton believes the radar technique could open the door for longer-life pavements that are engineered and constructed with tighter quality controls. That would save taxpayers "wads of money," he says.

(Images courtesy of Epic Inc.)

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Lyric Technologies, Inc.

Lyric Technologies, Inc.
1713 Broadmoor Drive, Suite 212
Bryan, TX 77802

Phone: 979.774.9511
Fax: 979.774.4611

Introducing the SIDARS Technology for use with Ground Penetrating Radar for Analysis of Pavement Layer Thickness, Composition, and Voids

- The Technology
- Data Collection
- Applications
- Analysis Examples

INSTRUCTIONS:

➢CLICK mouse or spacebar to advance.
➢PRESS backspace to view previous slide.
➢CLICK shortcut buttons to view specific sections.

SIDARS *calculates and numerically quantifies:*

- Layer Thickness
- Asphalt or Water Content
- Dry and Total Unit Weight
- Porosity or Voids in the Mineral Aggregate
- Percent Air
- Air Voids

- The Technology
- Data Collection
- Applications
- Analysis Examples

INSTRUCTIONS:

➢CLICK mouse or spacebar to advance.
➢PRESS backspace to view previous slide.
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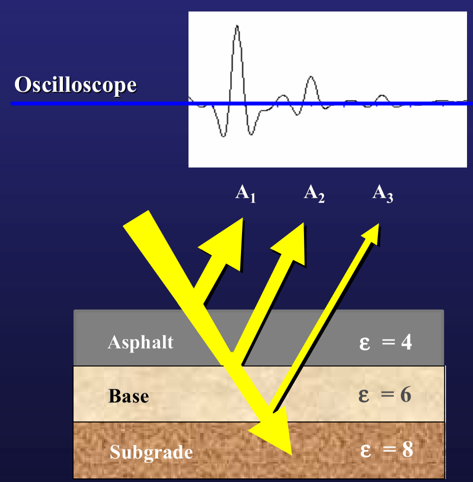
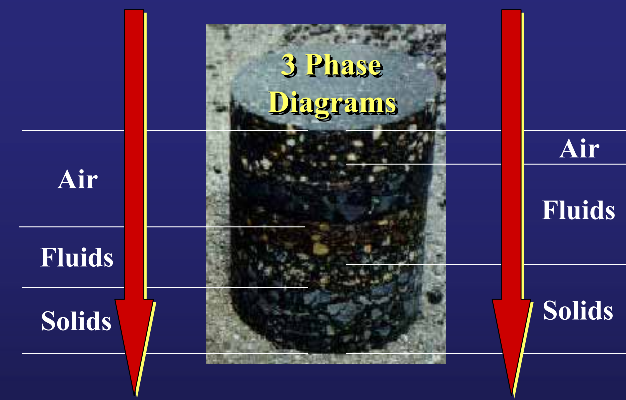
System IDentification Analysis of Radar Signals

Reflections at Interfaces of Differing Dielectric Properties





Material composition alters the speed of the radar wave creating the need for calibration cores. Our practice is to require both calibration and verification cores.

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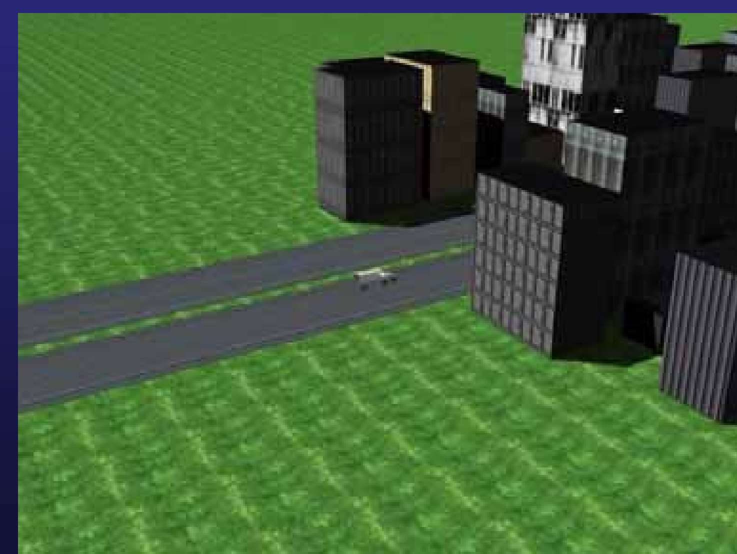
Data Collection

Data Collection



Antenna Footprint

The energy radiates out in an elliptical shape and returns signal reflections based on the properties of the area within the “footprint” of the antenna.

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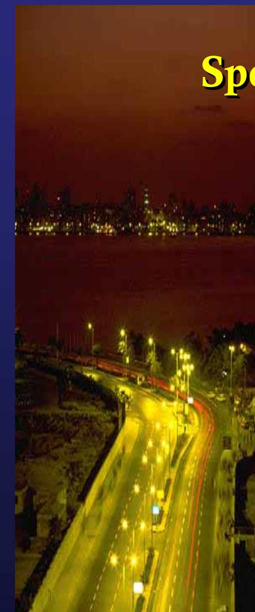
Specialized Applications



- Quality Assurance/Quality Control: New Construction
- General Assessment: Existing Pavements
- Asphalt Stripping and Oxidation
- Void Detection

May Require Specialized Equipment Based on Overall Objective Needs

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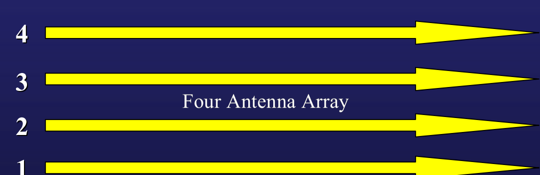
Quality Assurance / Quality Control by Layer: New Construction

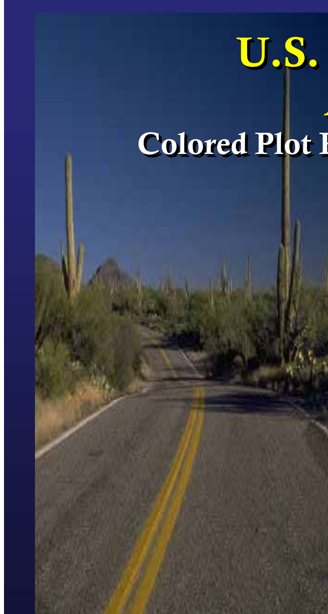
Displayed as Colored Plots Using Data Collected from Multiple Antennas Simultaneously



Or Strip Maps Using Single Antenna Run

U.S. 285 in New Mexico: Asphalt Surface

Colored Plot Reports Using Four Antenna Array



- Asphalt Content (%)
- Total Unit Weight (pcf)
- Voids in the Mineral Aggregate (%)
- Percent Air (%)
- Thickness (in)

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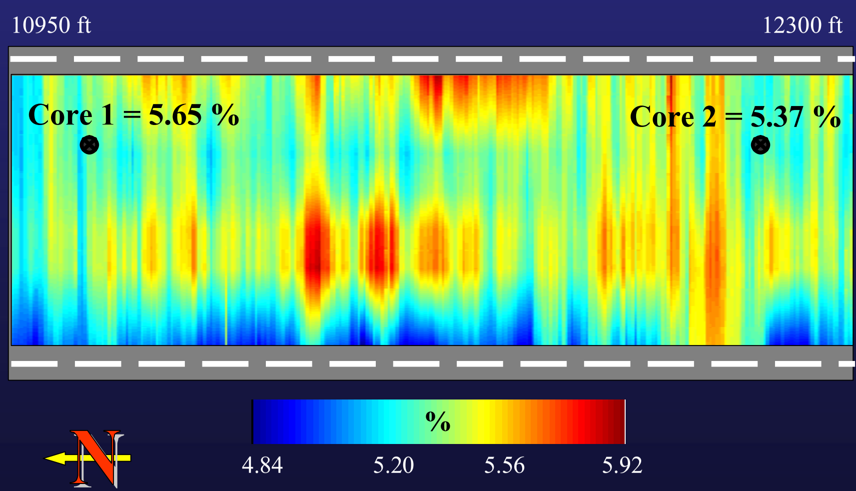
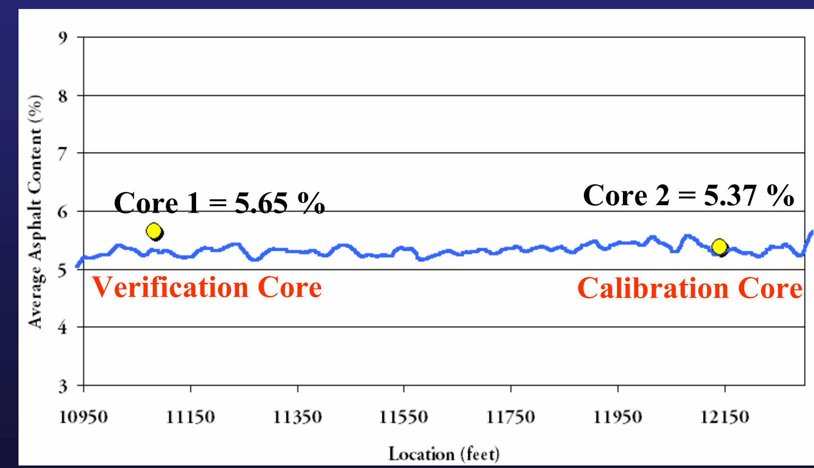
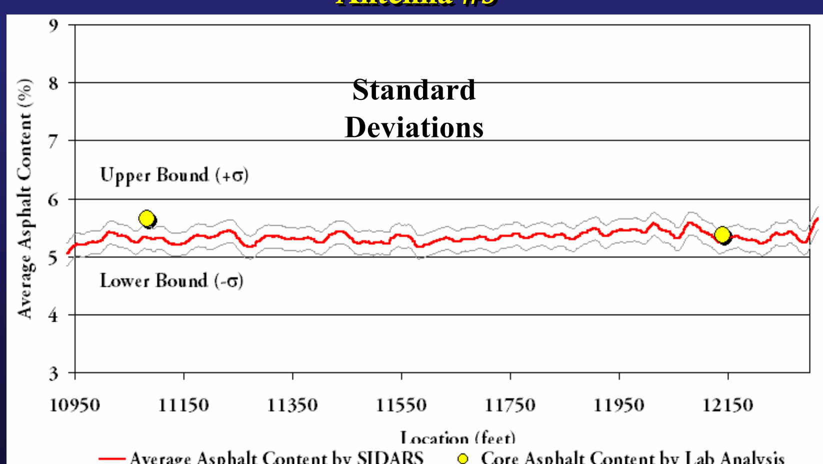
Asphalt Content (%)
New Mexico – U.S. 285 Southbound Lane



Asphalt Content (%)
New Mexico – U.S. 285 Southbound Lane
Antenna #3



Asphalt Content (%)
New Mexico – U.S. 285 Southbound Lane
Antenna #3



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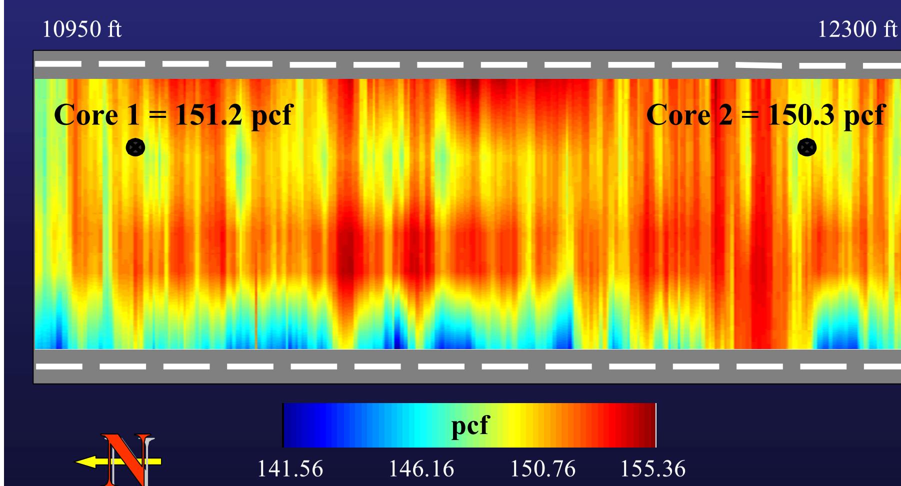
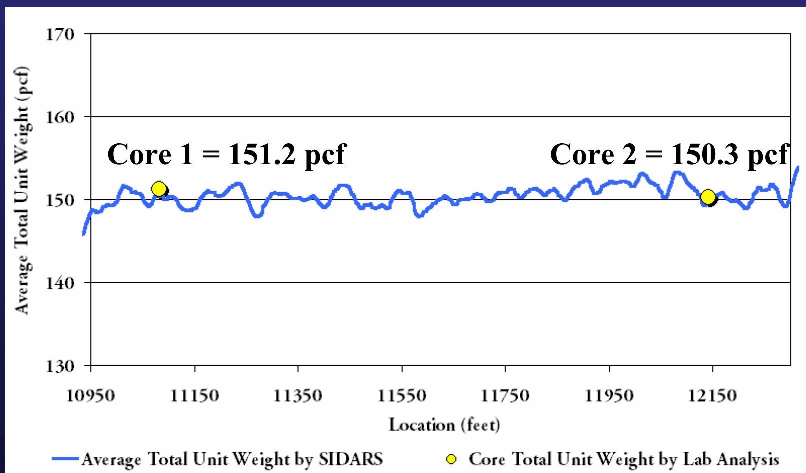
Total Unit Weight (pcf)
New Mexico – U.S. 285 Southbound Lane



Total Unit Weight (pcf)

New Mexico – U.S. 285 Southbound Lane
Antenna #3



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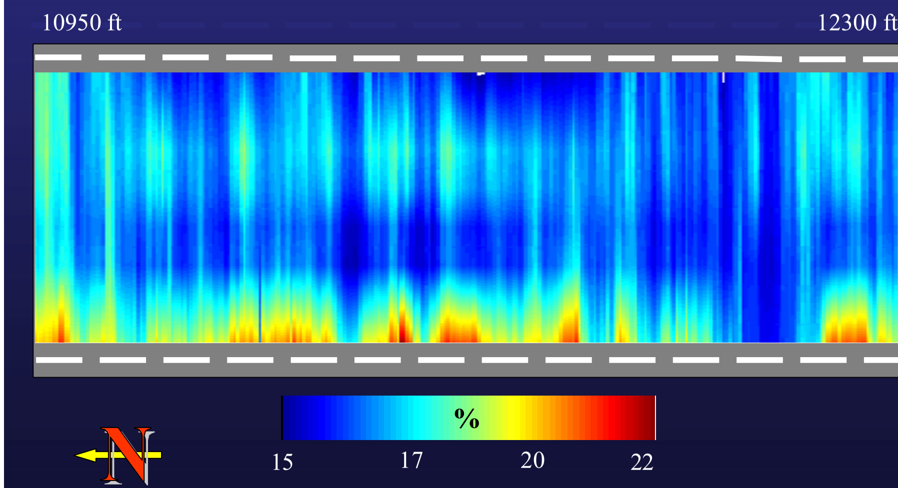
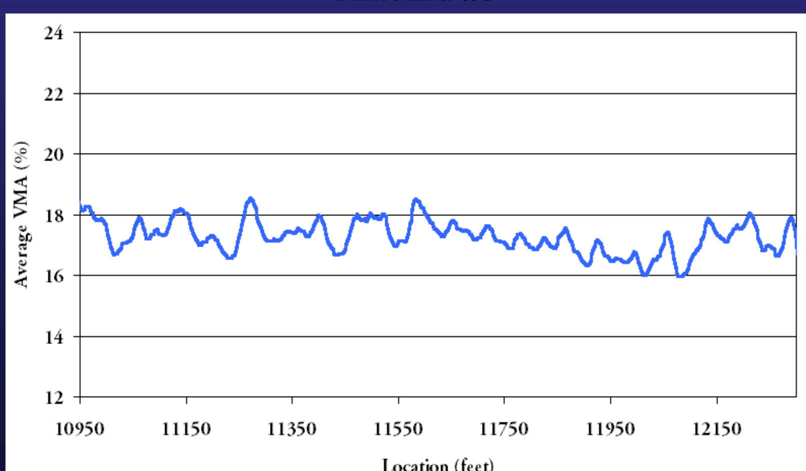
Voids in the Mineral Aggregate (%)

New Mexico – U.S. 285 Southbound Lane



Voids in the Mineral Aggregate (%)

New Mexico – U.S. 285 Southbound Lane
Antenna #3



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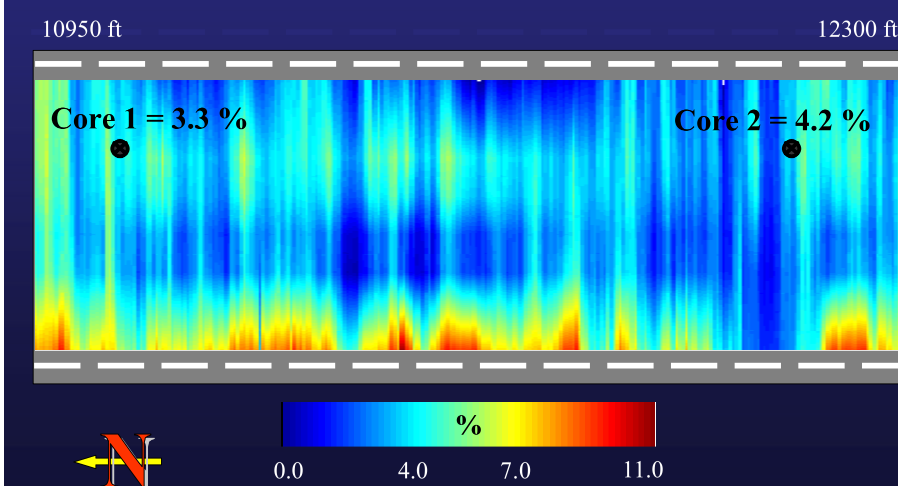
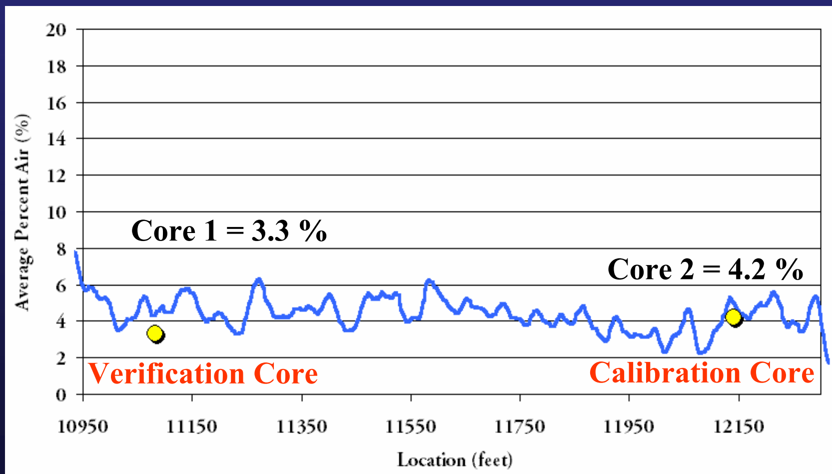
Percent Air (%)

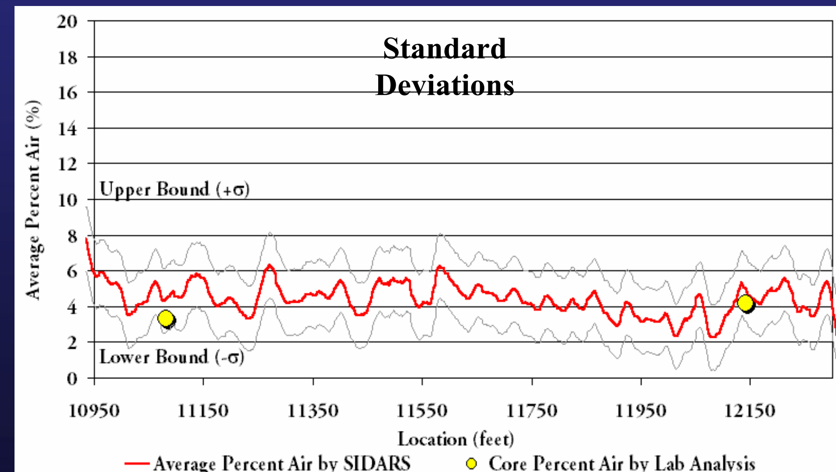
New Mexico – U.S. 285 Southbound Lane



Percent Air (%)
New Mexico – U.S. 285 Southbound Lane
Antenna #3



Percent Air (%)
New Mexico – U.S. 285 Southbound Lane
Antenna #3



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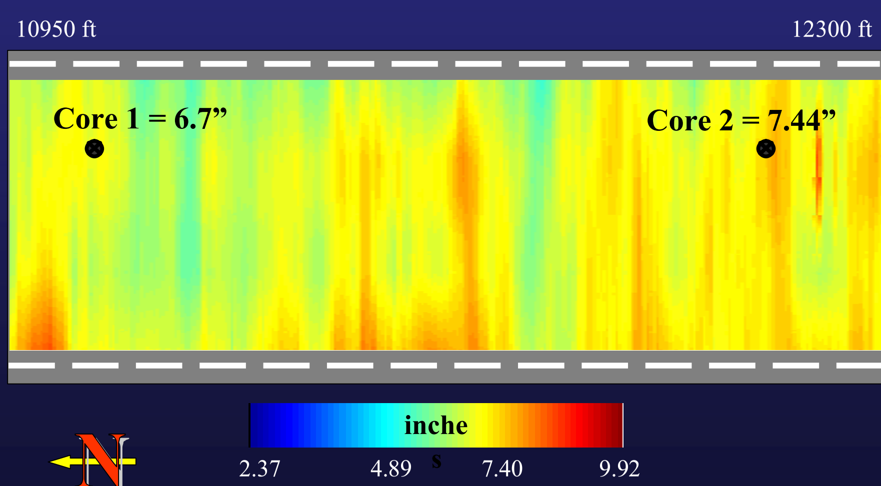
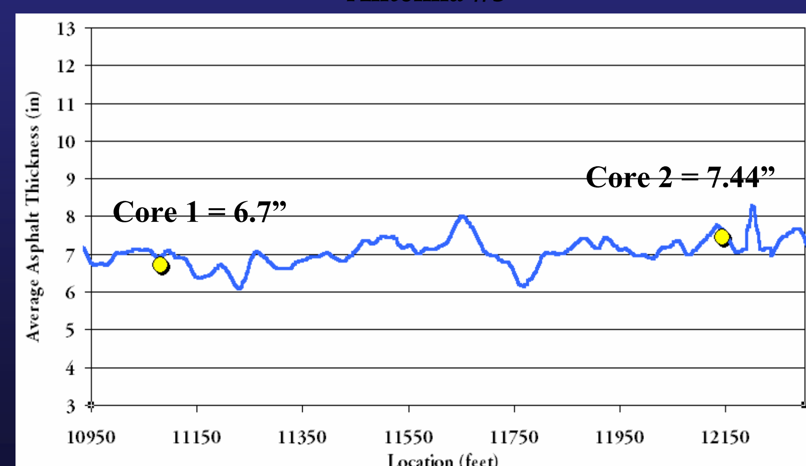
Thickness (in)
New Mexico – U.S. 285 Southbound Lane



Thickness (in)
New Mexico – U.S. 285 Southbound Lane
Antenna #3



Click to View Various Strip Map Cases

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Various Pavement Cases

Strip Map Reports Using Single Antenna

- Asphalt Content (%)
- Water Content (%)
- Total Unit Weight (pcf)
- Voids in the Mineral Aggregate
- Percent Air (%)
- Thickness (in)

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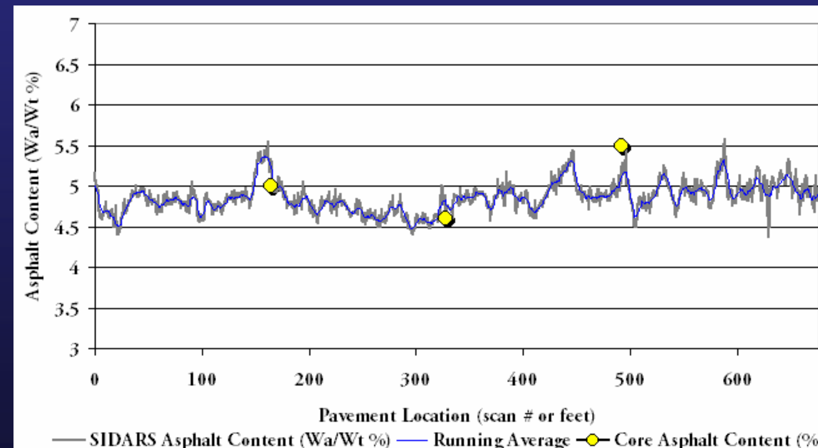
Asphalt Content (%)

Texas – State Highway 36 Asphalt Surface Layer



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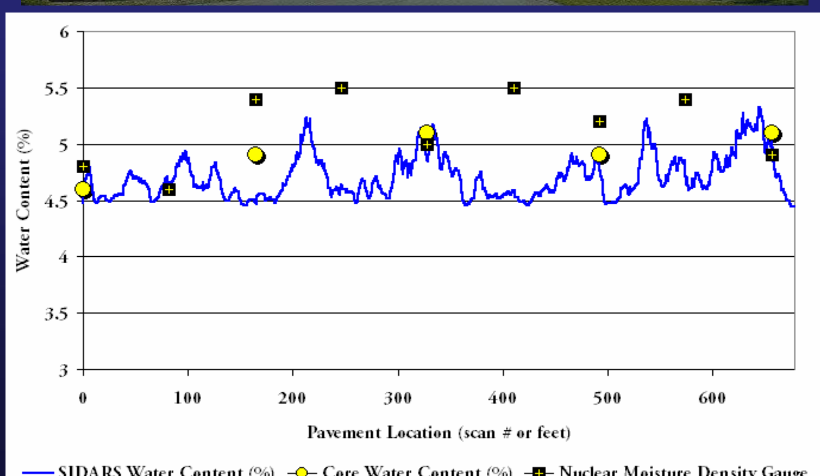
Water Content (%)

Texas Farm-to-Market 2693 – Limestone Flexible Base



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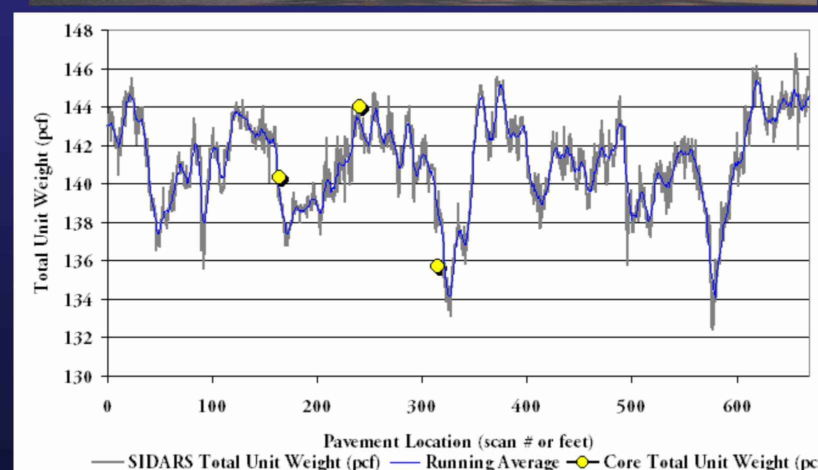
Total Unit Weight (pcf)

Texas Farm-to-Market 2821 – Asphalt Surface Layer



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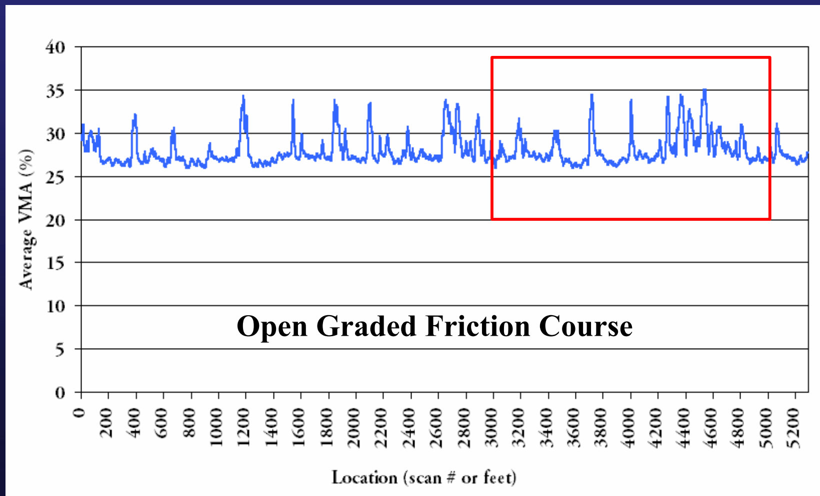
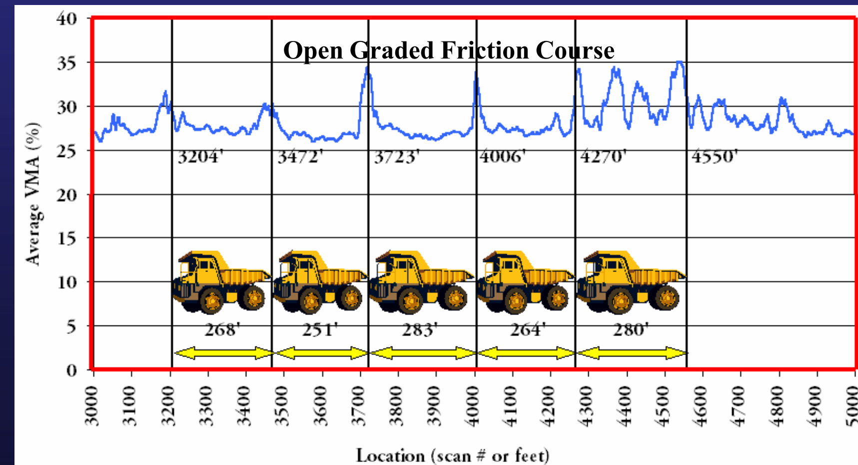
Voids in the Mineral Aggregate (%)

Florida – U.S. 441, Alachua County



Voids in the Mineral Aggregate (%)

Florida – U.S. 441, Alachua County, 3,000-5,000 ft



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Percent Air (%)

New Mexico – U.S. 285 Southbound Lane

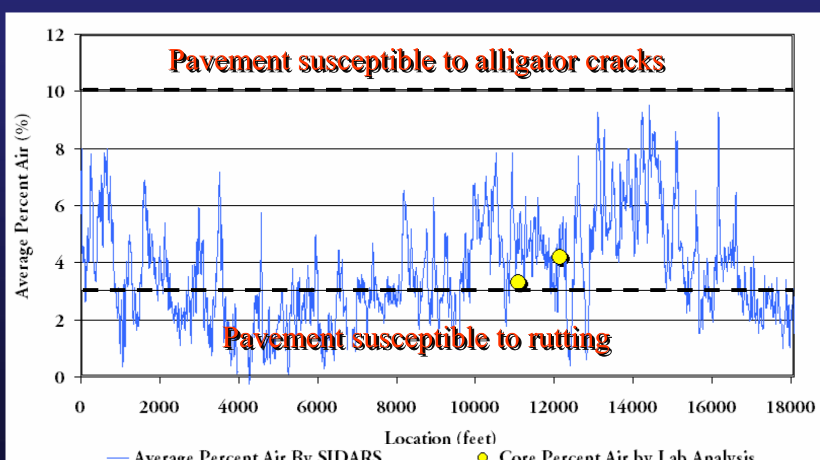

Photo: Courtesy of Mesa, PDC

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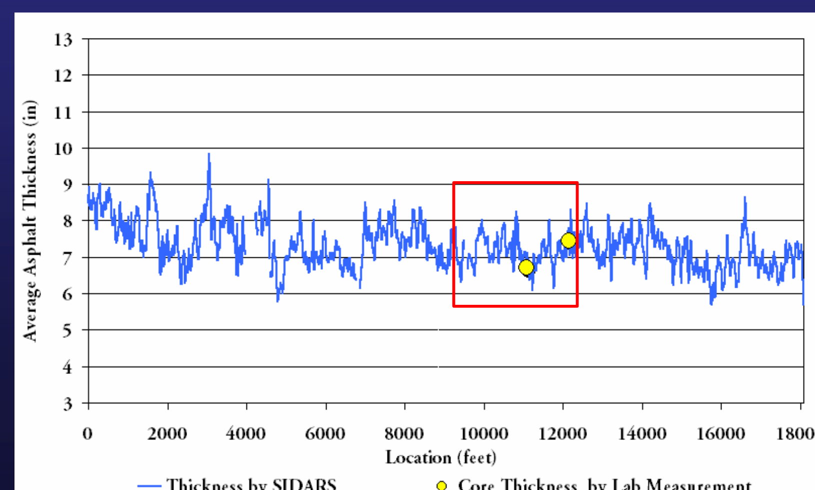
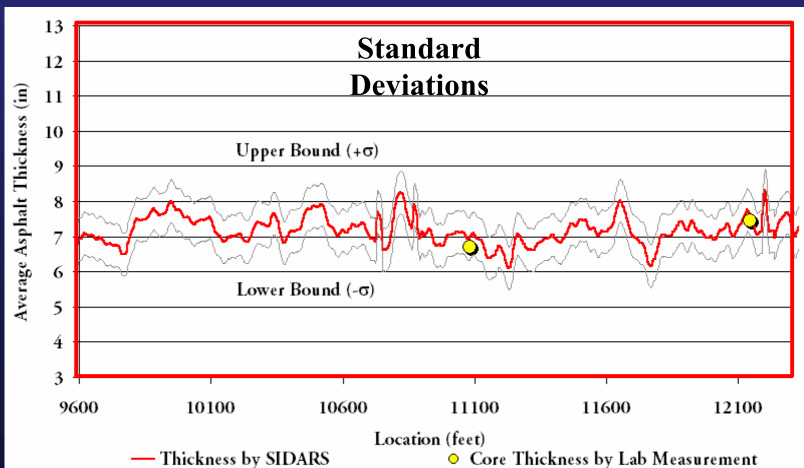
Asphalt Thickness (in)

New Mexico – U.S. 285 Southbound Lane



Asphalt Thickness (in)

New Mexico – U.S. 285 Southbound Lane, 9,600 – 12,300 ft



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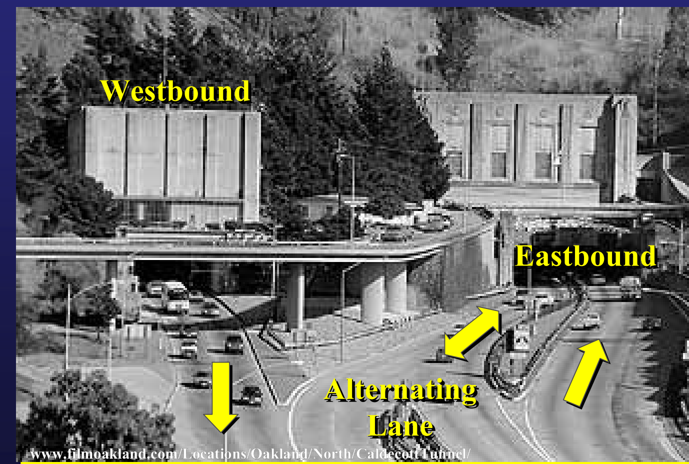
General Assessment: Existing Concrete Pavement

Caldecott Tunnel, California



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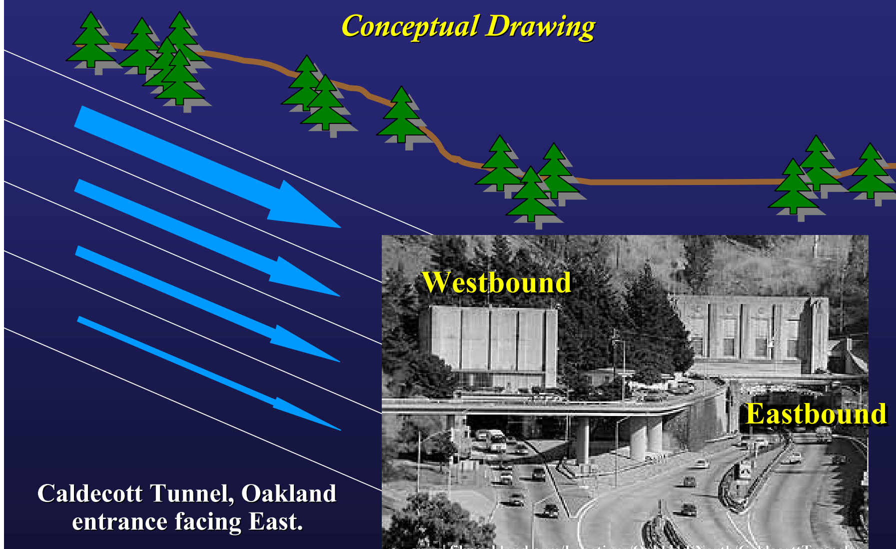
Caldecott Tunnel

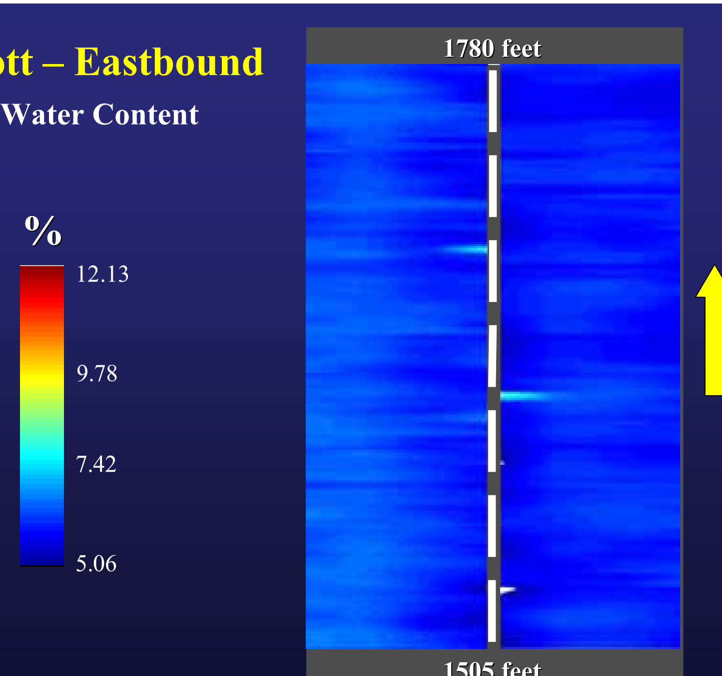
Conceptual Drawing

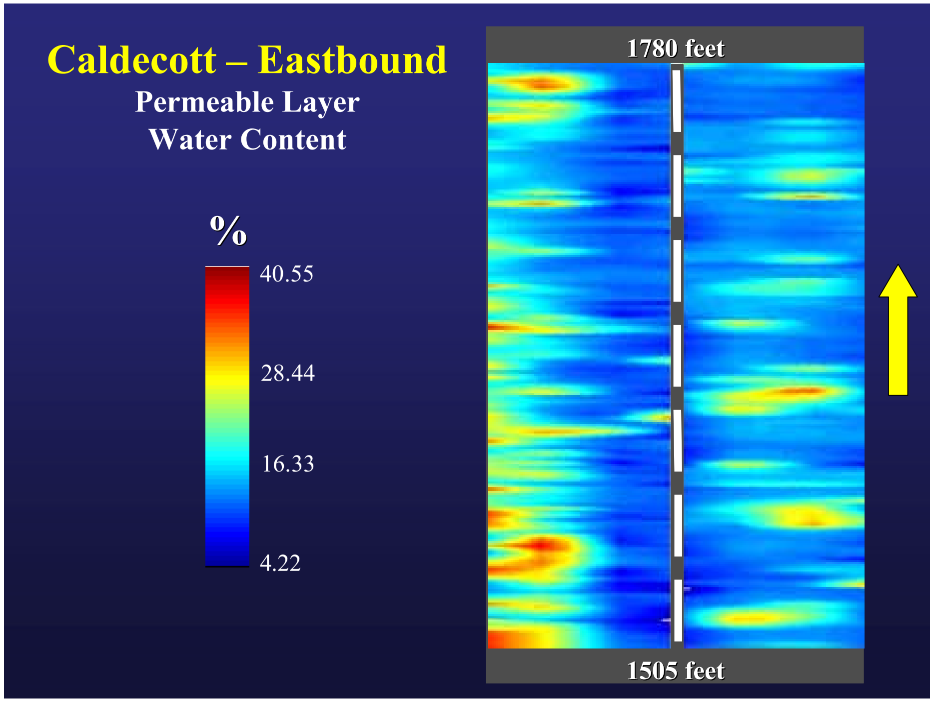


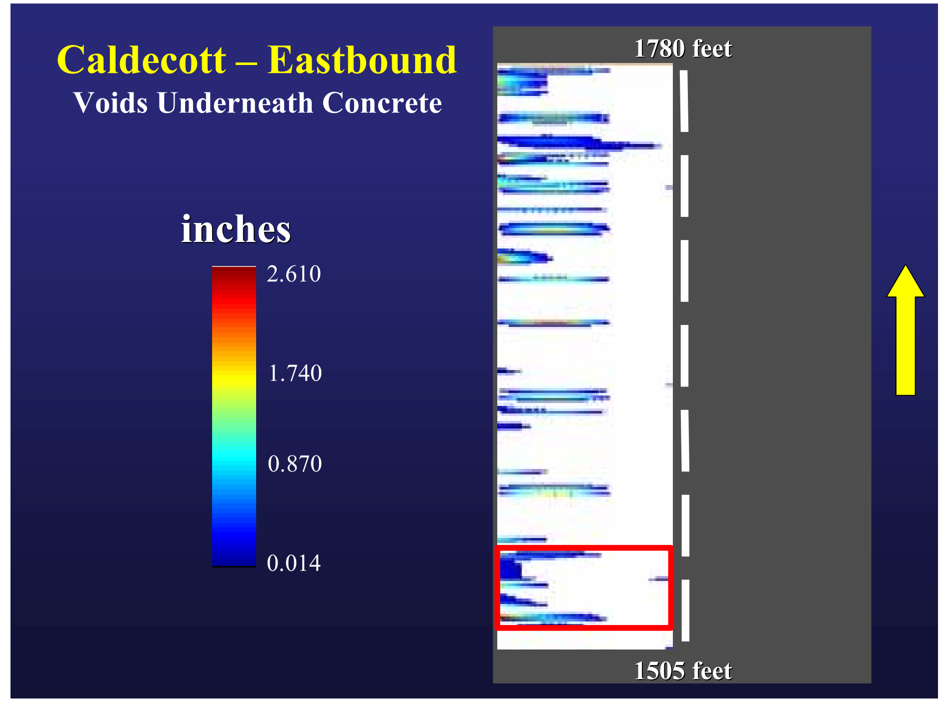
Caldecott Tunnel, Oakland entrance facing East.

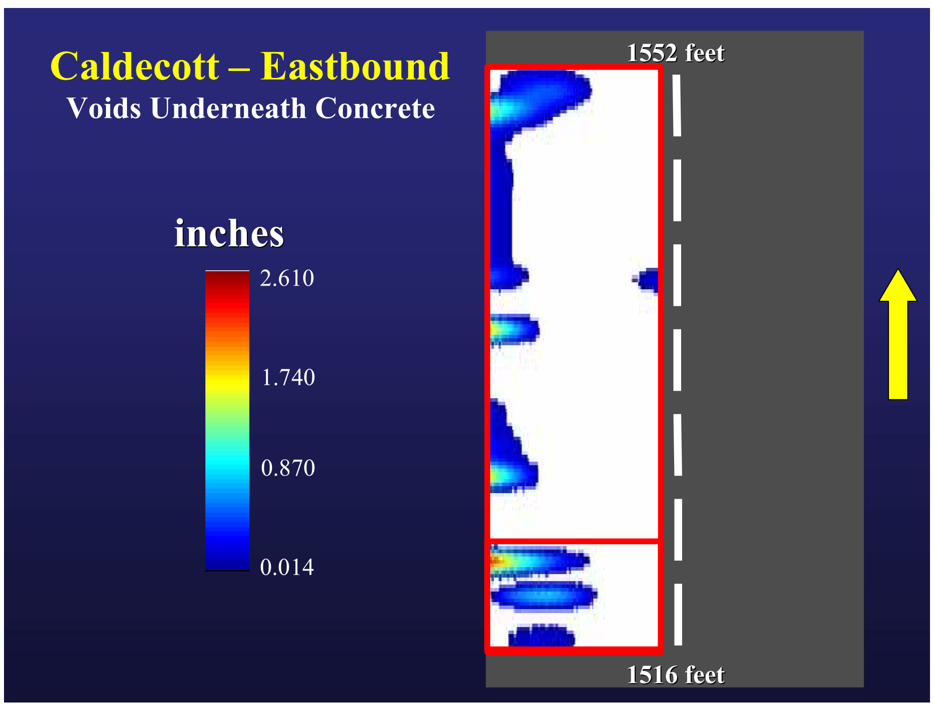
Caldecott – Eastbound

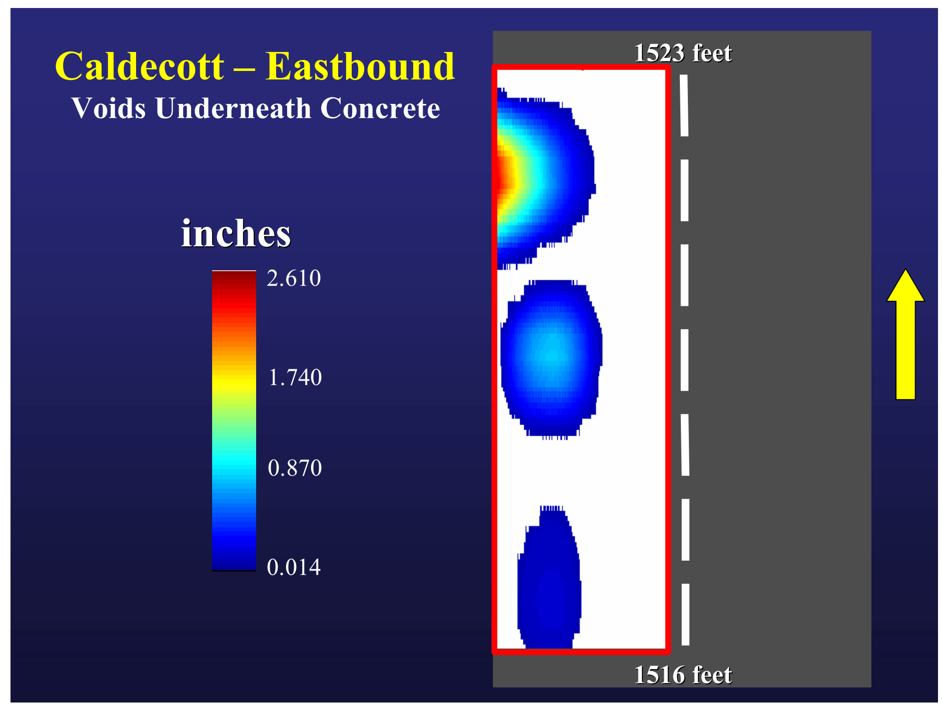
PCC Water Content



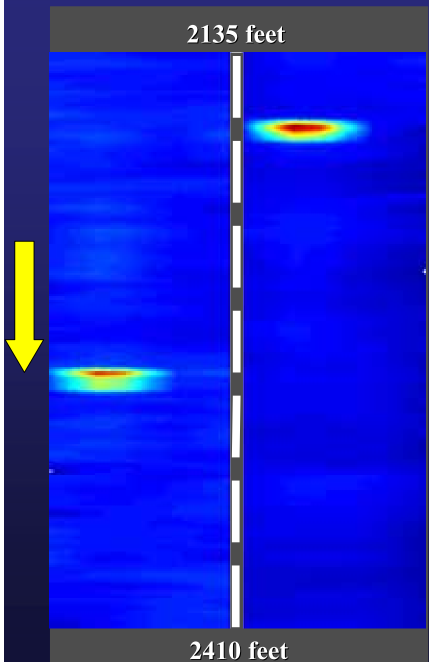

Caldecott – Eastbound
Permeable Layer
Water Content
%
40.55
28.44
16.33
4.22
1780 feet
1505 feet


Caldecott – Eastbound
Voids Underneath Concrete
inches
2.610
1.740
0.870
0.014
1780 feet
1505 feet

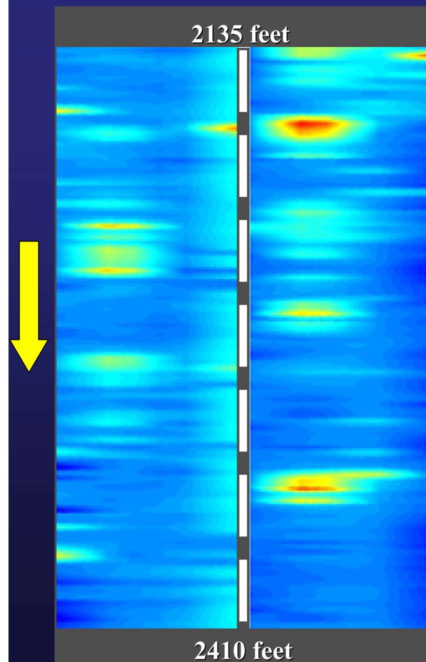

Caldecott – Eastbound
Voids Underneath Concrete
inches
2.610
1.740
0.870
0.014
1552 feet
1516 feet


Caldecott – Eastbound
Voids Underneath Concrete
inches
2.610
1.740
0.870
0.014
1523 feet
1516 feet

Caldecott – Westbound
PCC Water Content



Caldecott – Westbound
Permeable Layer Water Content



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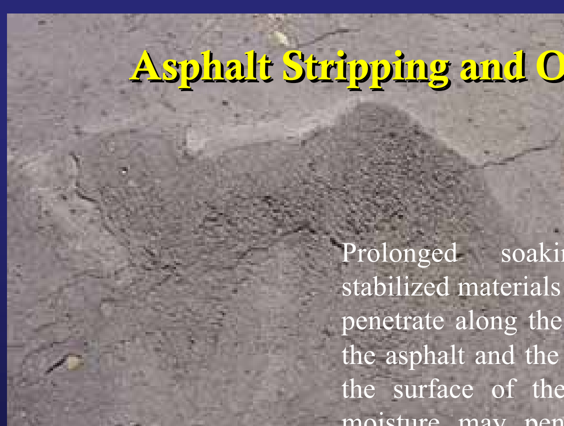
Asphalt Stripping and Oxidation



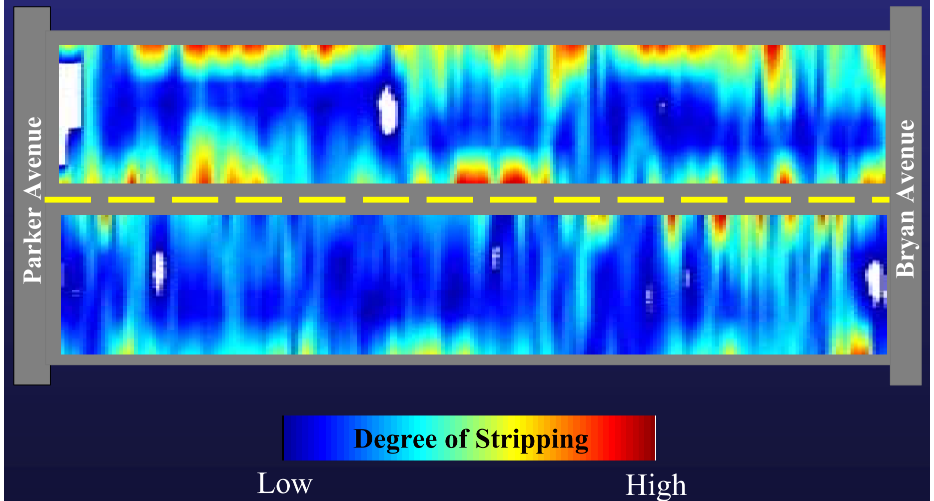
Prolonged soaking of asphalt stabilized materials causes moisture to penetrate along the interface between the asphalt and the aggregate and wet the surface of the aggregate. The moisture may penetrate the asphalt films by emulsion formation causing stripping and thus contributing to raveling and weathering.

A Pavement Moisture Accelerated Distress (MAD) Identification System, Users Manual – Volume 2. Report No.FHWA/RD-81/080

Asphalt Stripping
27th Street Between Parker and Bryan Avenue, Bryan Texas

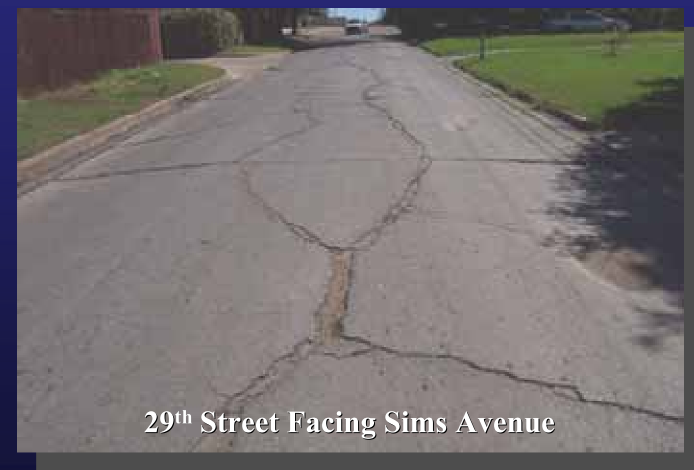
Degree of Asphalt Stripping

27th Street Between Parker and Bryan Streets, Bryan, Texas



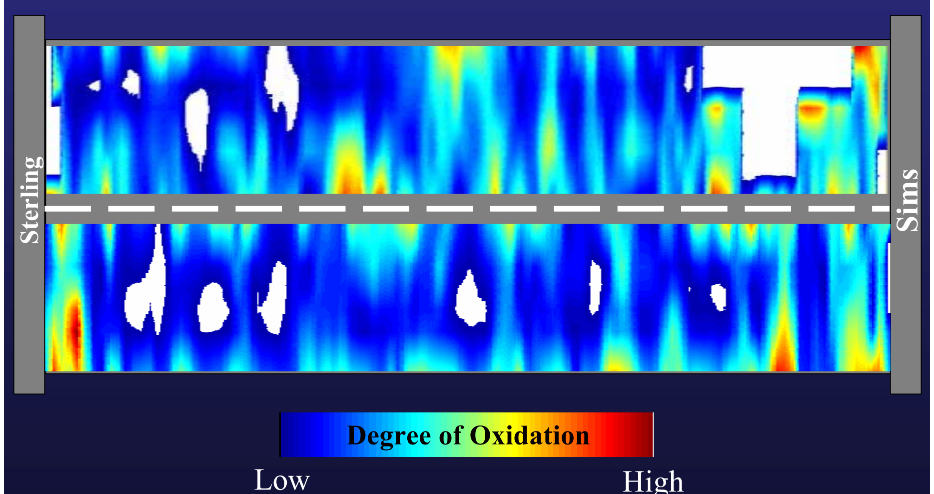
Oxidation

29th Street Between Sterling and Sims, Bryan, Texas



Degree of Oxidation

29th Street Between Sterling and Sims, Bryan, Texas



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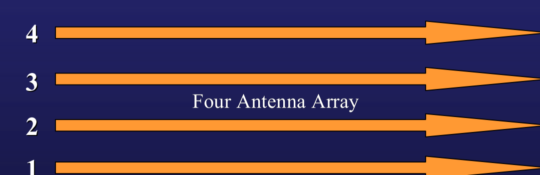
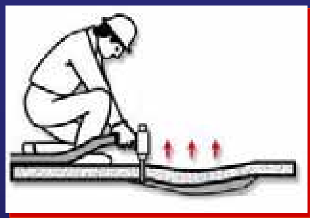
Displayed as Colored Plots Using Data Collected from Multiple Antennas Simultaneously



Lyric has teamed with URETEK, USA to find and fill air voids. Lyric has developed proprietary software to find air voids under concrete pavements. URETEK fills the voids with polyurethane foam.

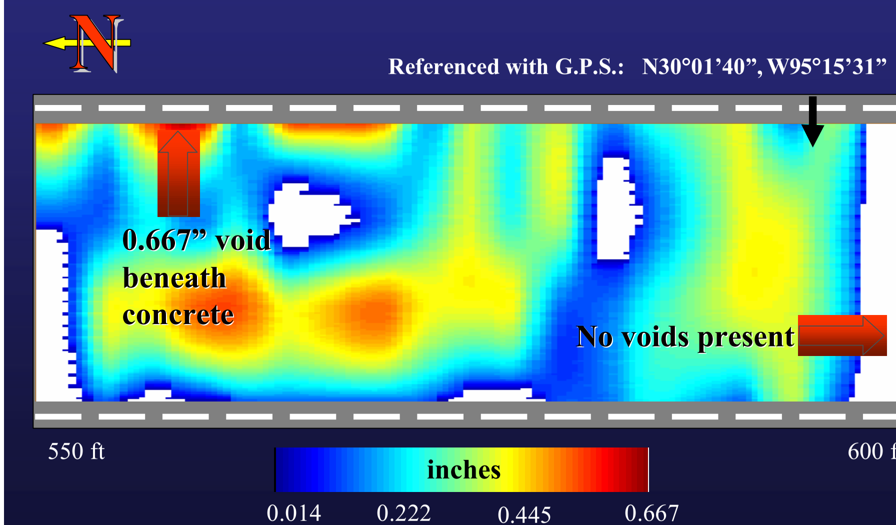


URETEK, USA
and the URETEK Method

- Built the 4-antenna HyperOptics van for highway speed, lane-width detection of void conditions under concrete pavements using Lyric software.
- Patented technology employs expanding high density polyurethane foam, injected through drilled holes in the concrete to lift, realign, underseal, and void fill.
- Uretek USA, Inc. has repaired highways, roads, airport runways, commercial buildings, industrial foundations, parking areas and a broad spectrum of other concrete slab-on-grade facilities.

Void Detection – Concrete Pavement
Houston, Texas – U.S. Highway 59, Southbound

Referenced with G.P.S.: N30°01'40", W95°15'31"



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