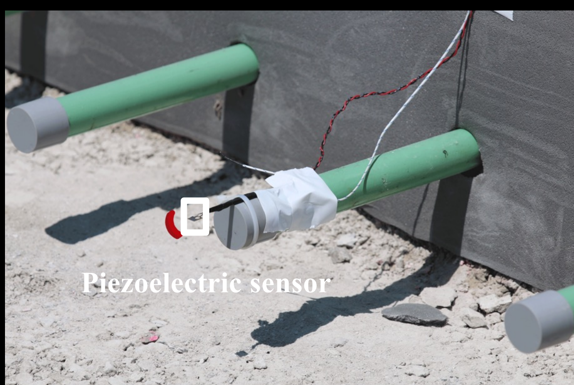
Intelligent Infrastructure Innovations



Luna Lu
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Reilly Professor, Lyles School of Civil Engineering
Director, Center for Intelligent Infrastructure
Purdue University ; luna@purdue.edu

PURDUE UNIVERSITY | Lyles School of Civil Engineering

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Why Intelligent Infrastructure?

The steam plant explosion on 5th Ave.
In NYC in July 2018

Pittsburgh bridge collapse Jan 2022

Potholes everywhere

- 7.5% of bridges are structural deficient, and 43% are more than 50 years old
- 40% of roads in US are poor conditions, costing $141B - $621 per driver/year
- Traffic jams caused by poor infrastructure conditions waste 4 billion hours and nearly 3 Billion gallons of gasoline a year

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Transform Existing Transportation Infrastructure Systems

- How can we transform our existing infrastructure to respond to the rapid technology growth in transportations, climate change and data security?
- How to achieve *safety, sustainability, resiliency and adaptivity* of the overall complex and interconnected infrastructure system?
- How to integrate digital technology into infrastructure space and upskill the workforce?
- How to achieve a greater equitable system for historically underserved communities and rural areas?

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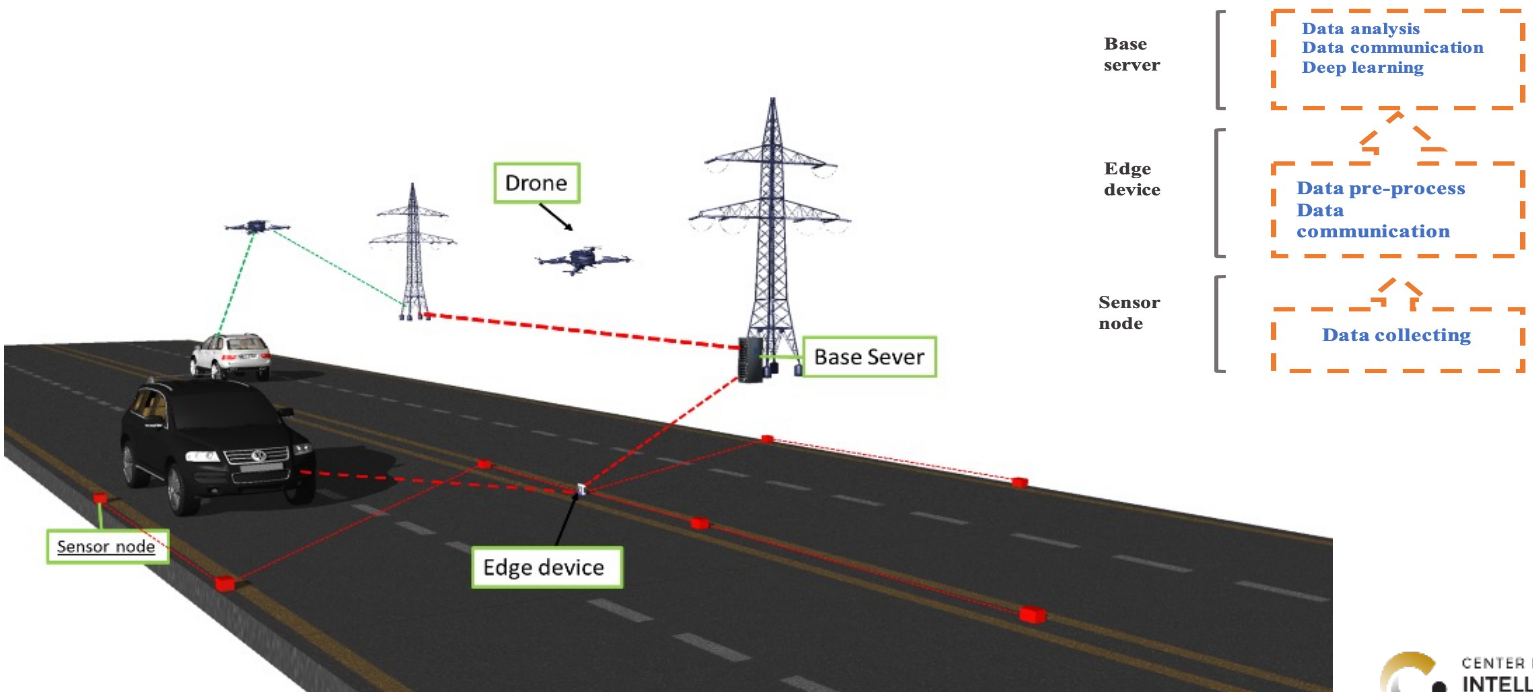
- Enable autonomous, sustainable and adaptive infrastructure
- Establish a leading role in research and education in intelligent infrastructure
- Provide a focal point for federal, state and private industry to engage
- Develop a platform for Purdue faculties with different expertise to collaborate



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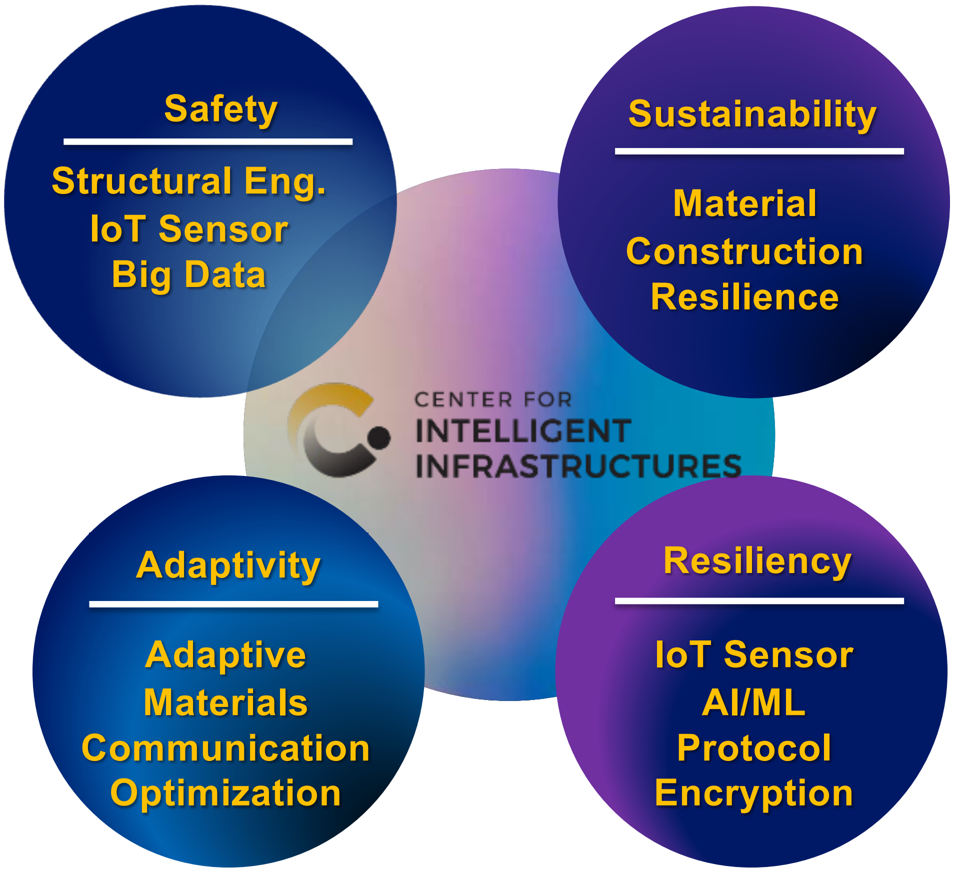

- ***4 Research Thrusts***
- ***35 Faculty and Research Professors***
- ***100 Postdoc and PhD Students***
- ***> 20 private and public partners***

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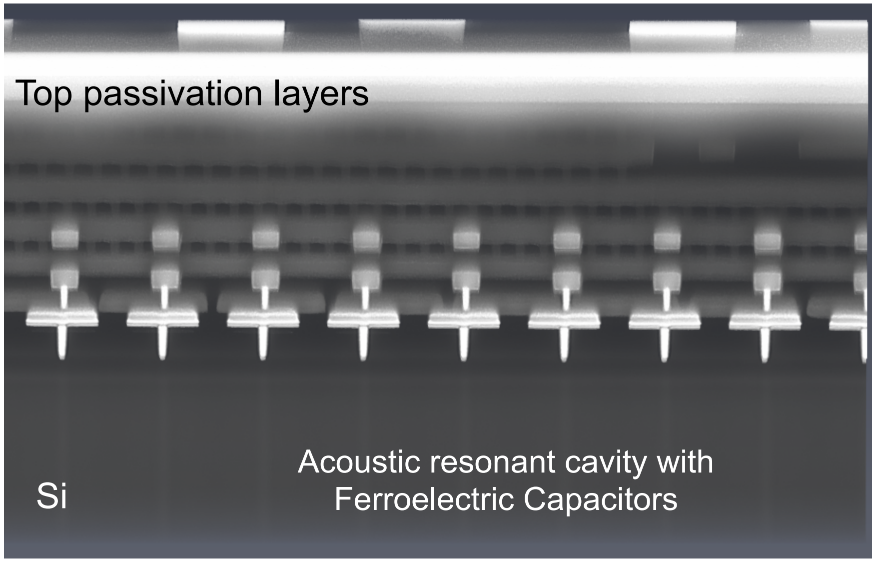
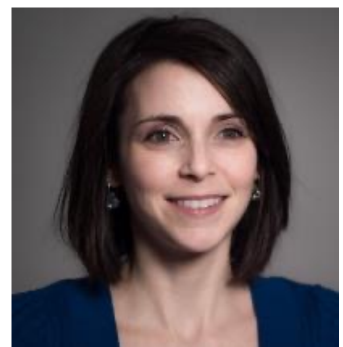
High Performance MEMs Sensor



High performance MEMS sensor enabling LiDAR and GPS and other vehicle positioning technology



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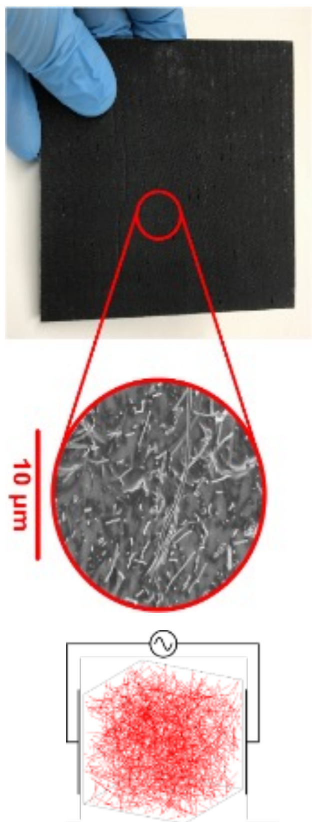
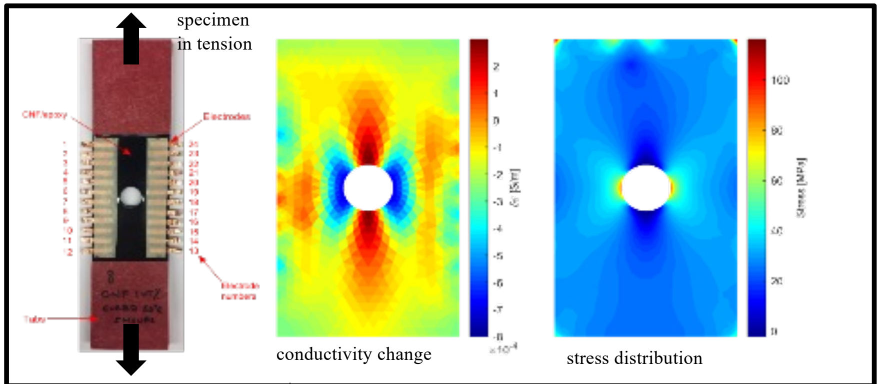
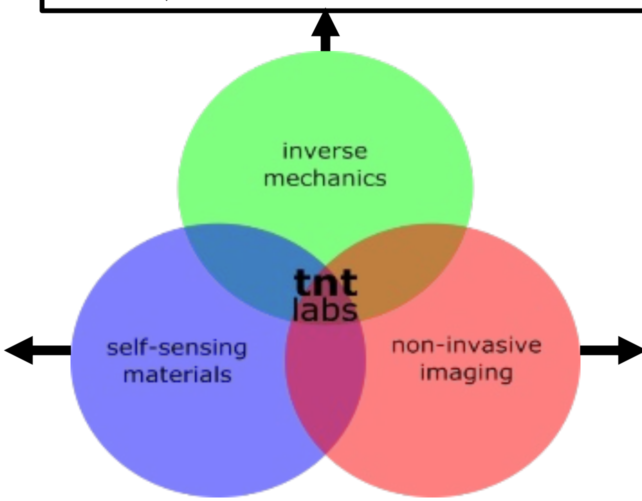
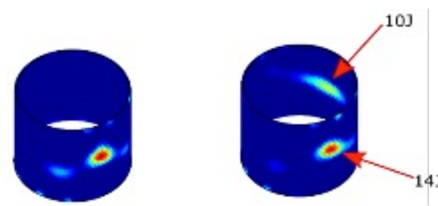
Smart Sensors



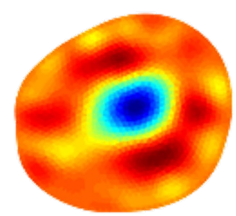




Low-cost carbon fiber sensors for failure detection



impact detection in a composite tube



non-invasive detection
of orthopedic implant failure

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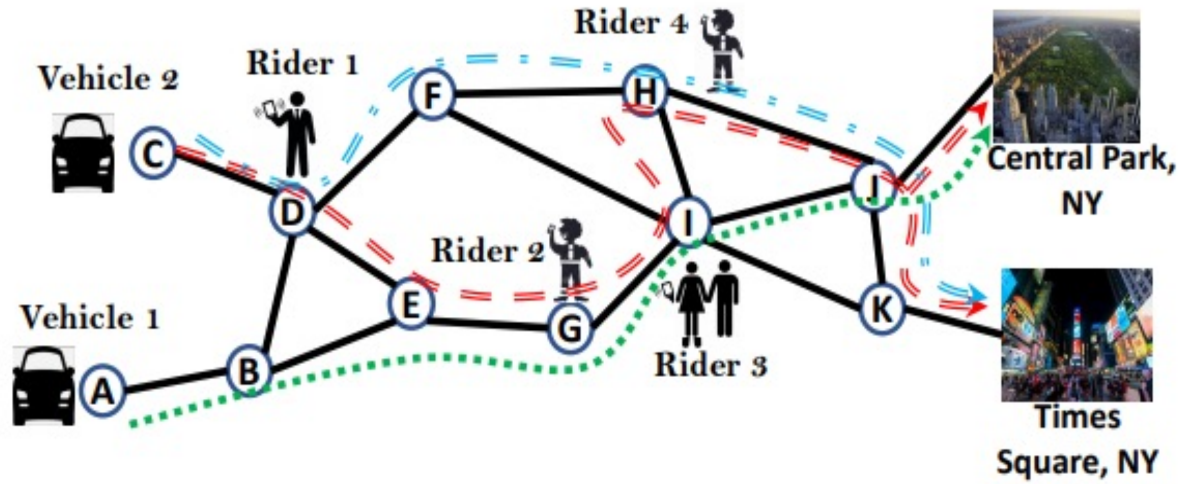
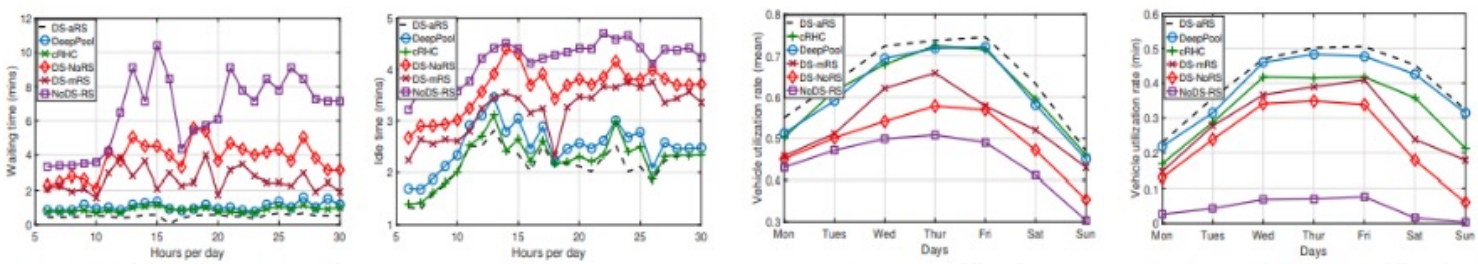
Communication Networks – New York City

Use machine learning for ride-sharing in New York City





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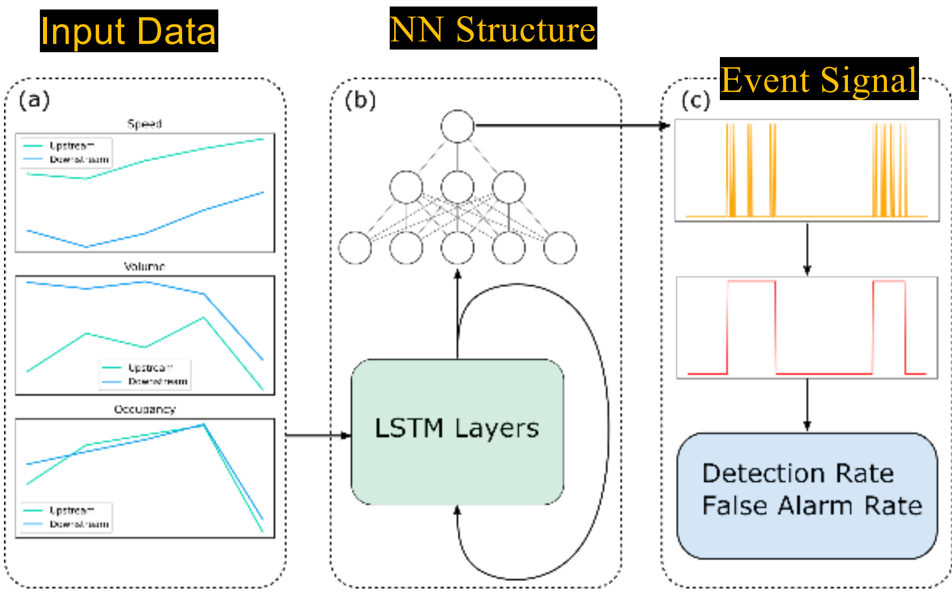
Traffic Automation - San Francisco Highway



Supported by California DOT & DOE Argonne National Lab

Objective: detect traffic incidents given loop detector measurements.

Challenges: incident-related traffic patterns vary; measurements could be noisy or faulty.

Methods: use LSTM to classify the current time slice as incident or non-incident based on its 2-minute traffic profile history; group incident time slices to form individual events.

$$DR = \frac{\text{Number of correctly detected incidents}}{\text{Number of total incidents}}$$

$$FAR = \frac{\text{Number of falsely detected incidents}}{\text{Number of detected incidents}}$$

Testing results

Data: California, I-80, District 4, March to May 2019

Scores: DR = 0.88; FAR = 0.09

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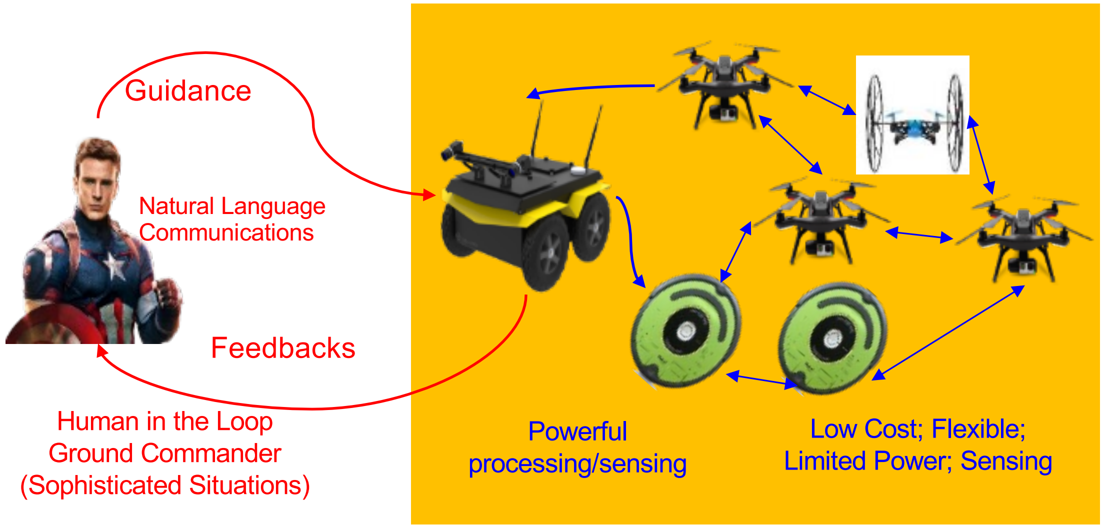
Machine Learning for Air Traffic Safety & Mobility

AI-assisted Multi-Agent Autonomy with Human-in-the-Loop
Northrop Grumman Corporation



https://www.purdue.edu/newsroom/releases/2019/Q2/

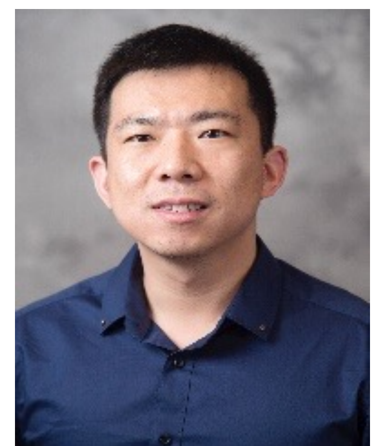
Secure and Safe Assured Autonomy
NASA University Leadership Initiative

North Carolina Agricultural and Technical State University
Georgia Tech
ALAKA'I TECHNOLOGIES
GENERAL ATOMICS AERONAUTICAL

Image credit: NASA Illustration/Lillian Gipson

PURDUE UNIVERSITY
Aurora FLIGHT SCIENCES A Boeing Company
NORTHROP GRUMMAN

Leading PI:
Shaoshuai Mou
Purdue University



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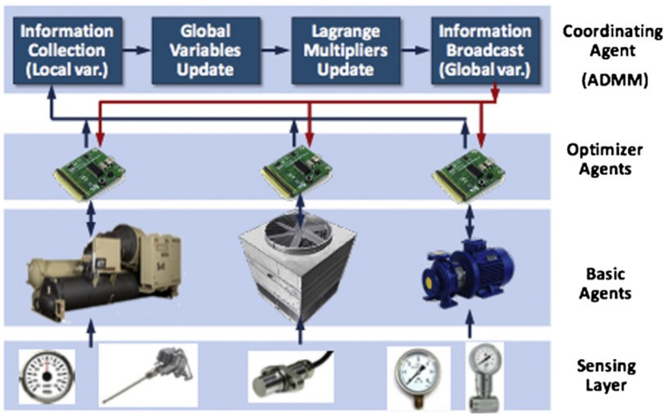
Energy Efficient Building Systems

Agent-Based Control Architecture



Purdue Living Laboratories with Retrofitted Air/Radiant Floor Systems

Agent-based plug-and-play building control:

- Multi-agent system modeling and control framework
- Distributed optimization solution algorithms
- Implemented in Purdue Living Labs
- 23% reduction of electricity cost based on actual data

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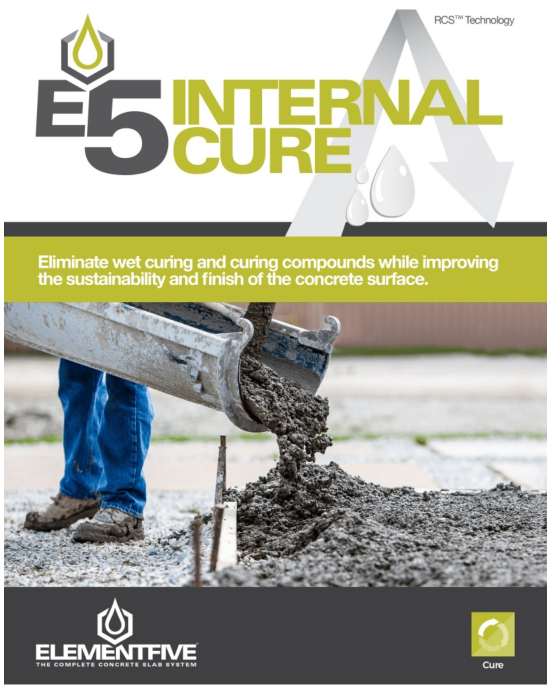
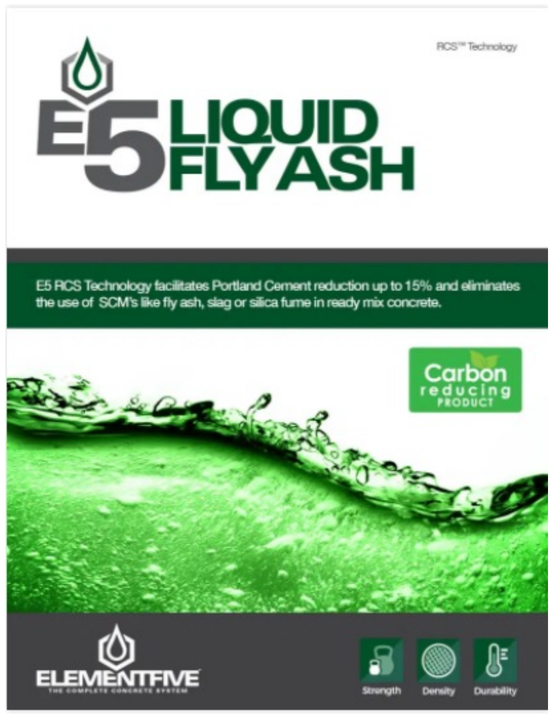
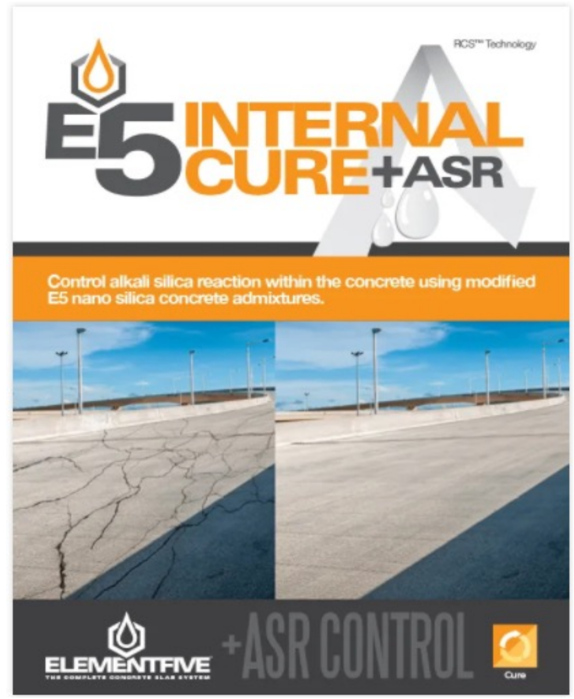
Self-healing Concrete

E5^{TM} Nano-silica for self-healing concrete

- Nano-silica admixture (E5^{TM}) for high performance and low carbon concrete, Specification Products, Indianapolis, IN







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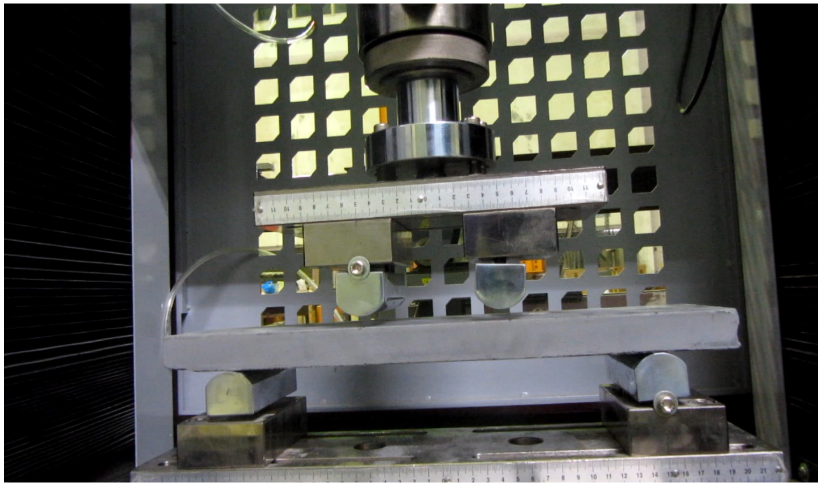
Self-healing Concrete for Improved Pavement Durability

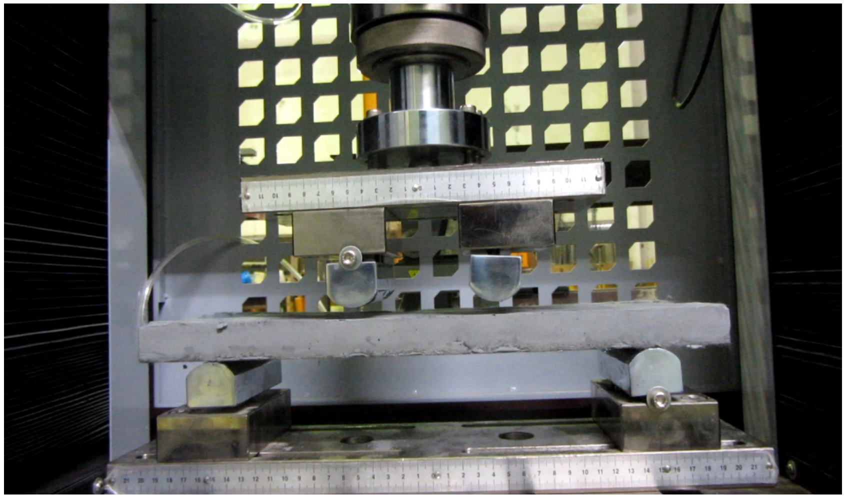
- **Conventional concrete pavement** suffers from **freeze- thaw deterioration in** northern regions of the United State.

- There are substantial materials and labor costs associated with concrete rehabilitation.

conventional concrete under loading



SHCC under loading



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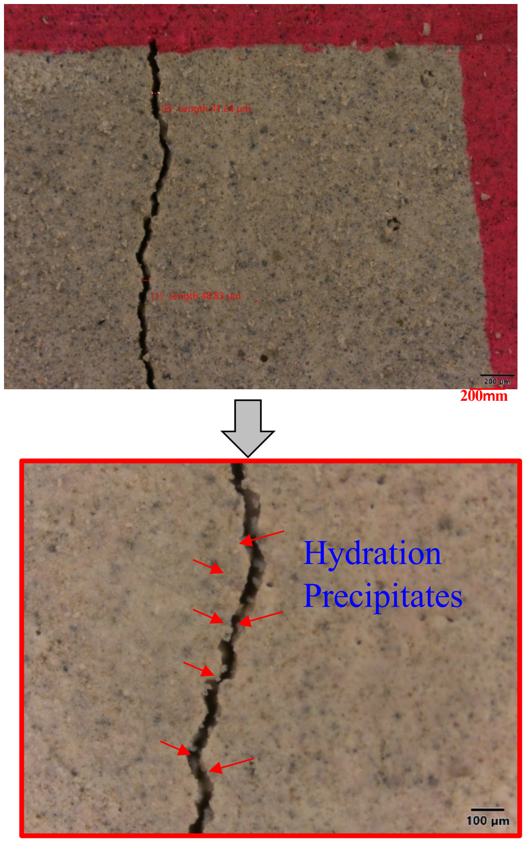
Microscope observation - 0.3% E5-SHCC

Preloaded



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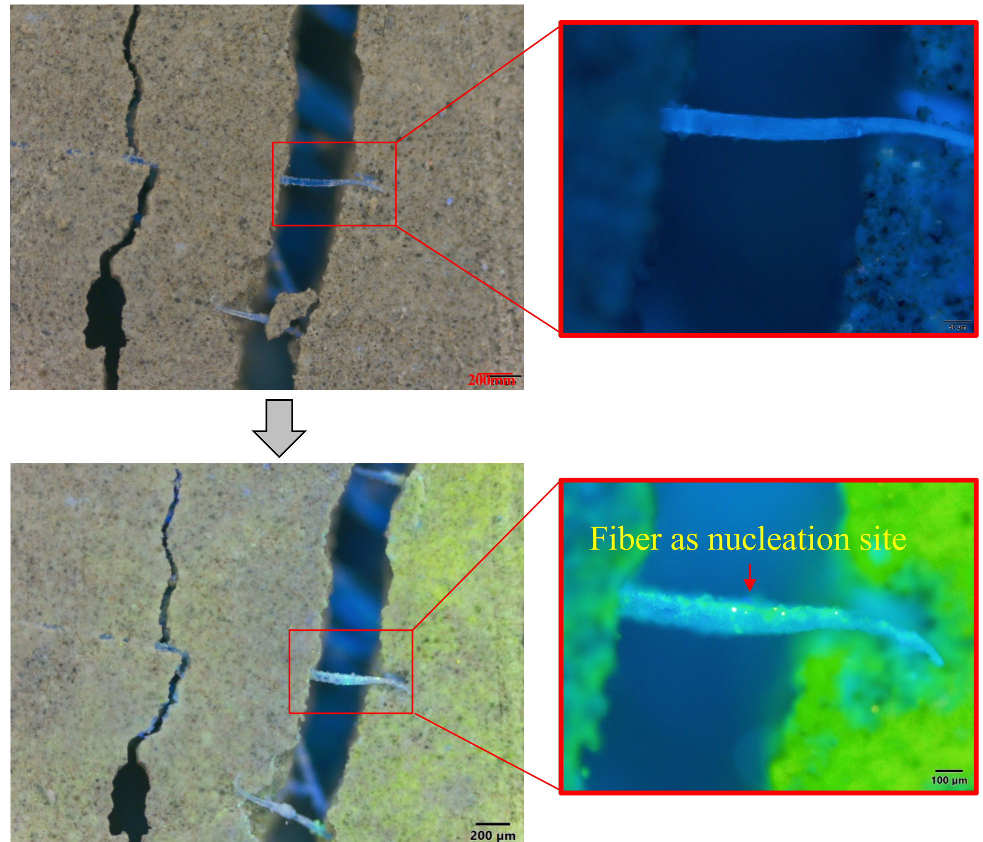

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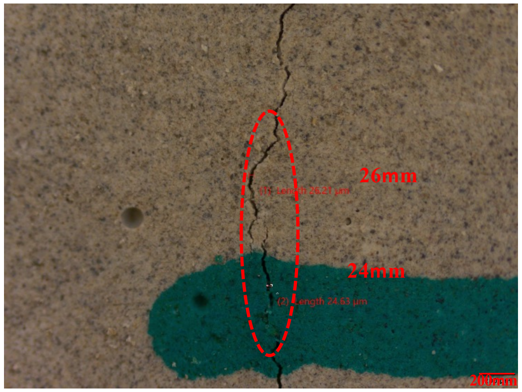
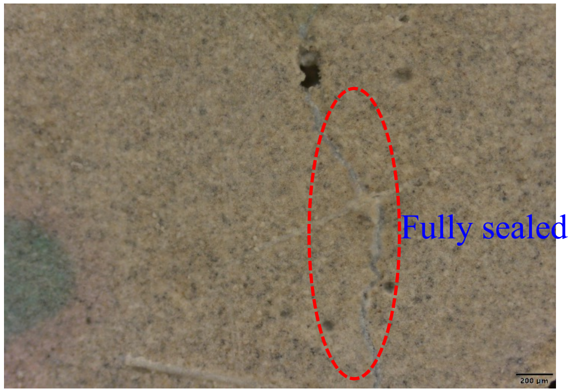
Microscope observation - 0.3% E5-SHCC

Pre-cracked

Two wet-dry cycle (8 days)





200mm

200mm

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Healed crack - 0.3% E5-SHCC

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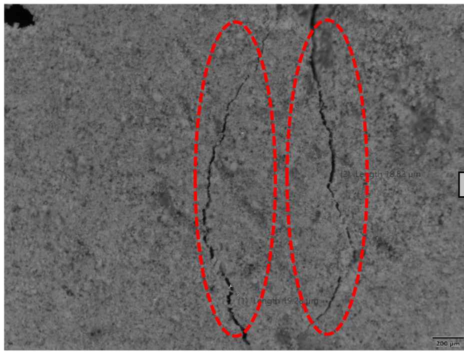
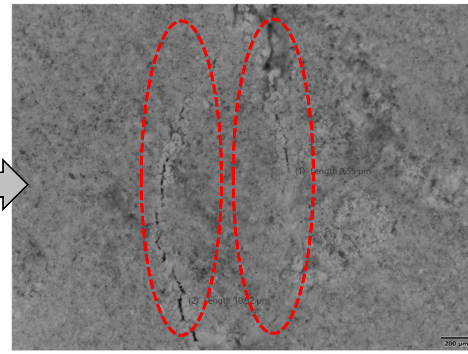
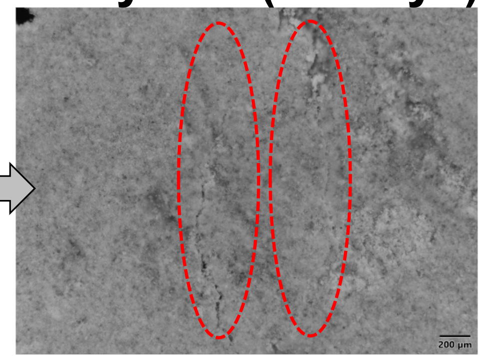


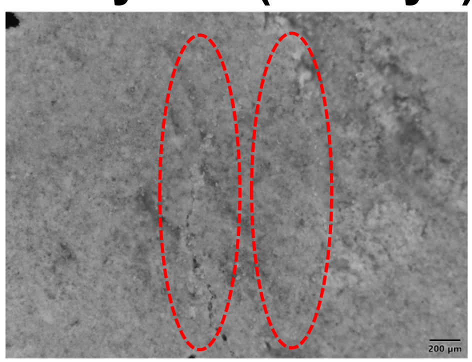
2 cycles (8 days)



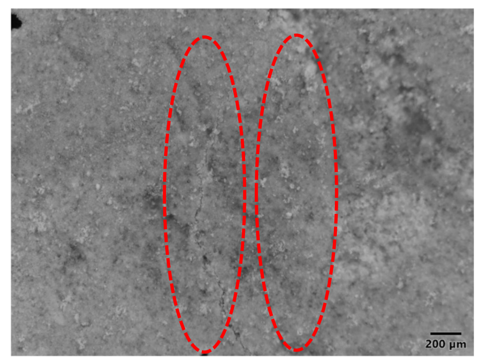
3 cycles (12 days)



5 cycles (20 days)



7 cycles(28 days)



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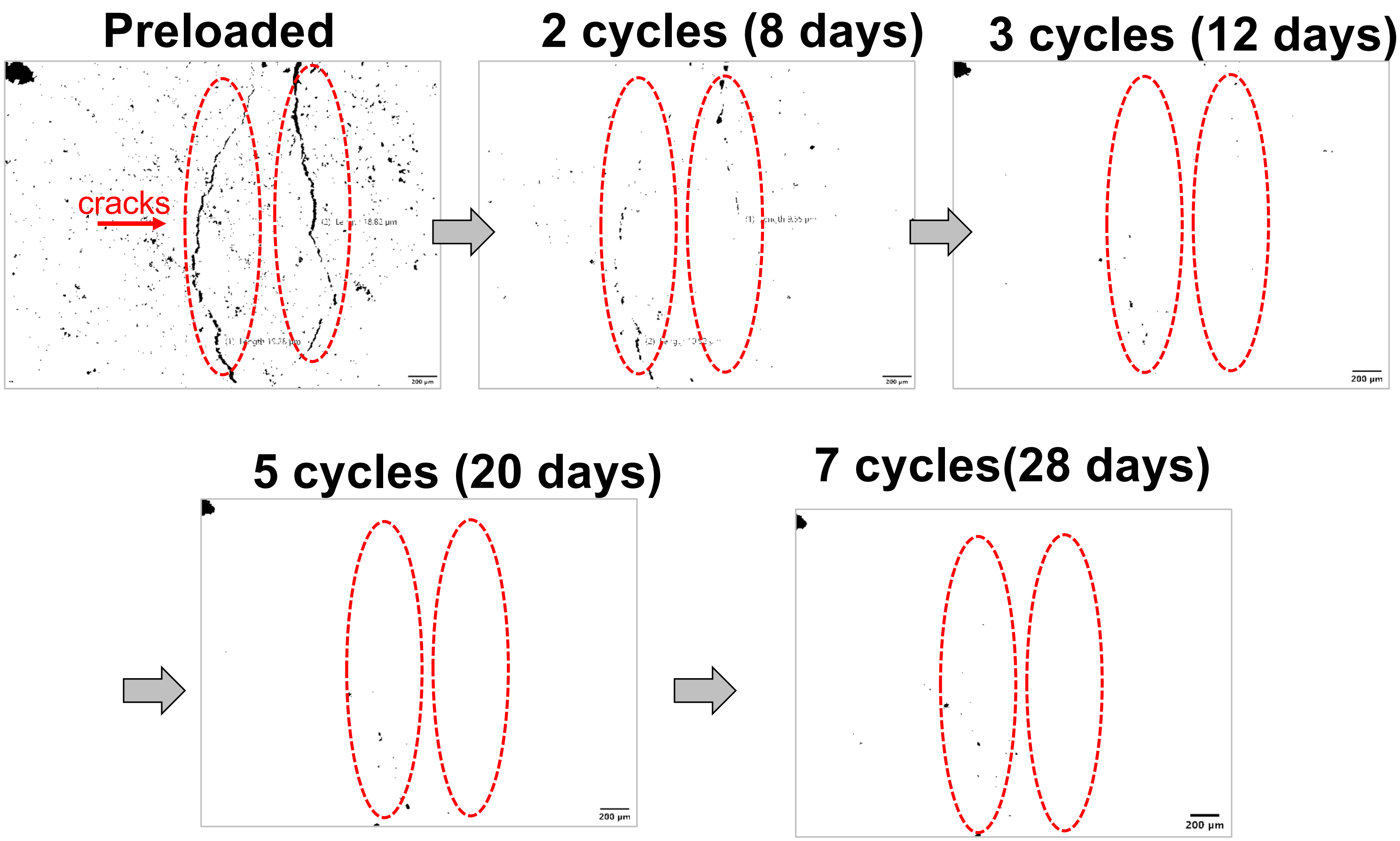
Healed crack - 0.3% E5-SHCC



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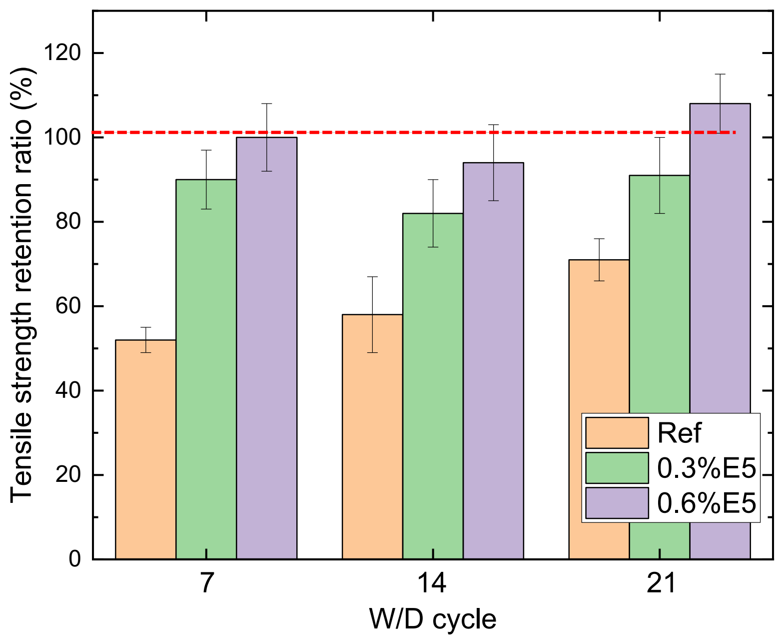
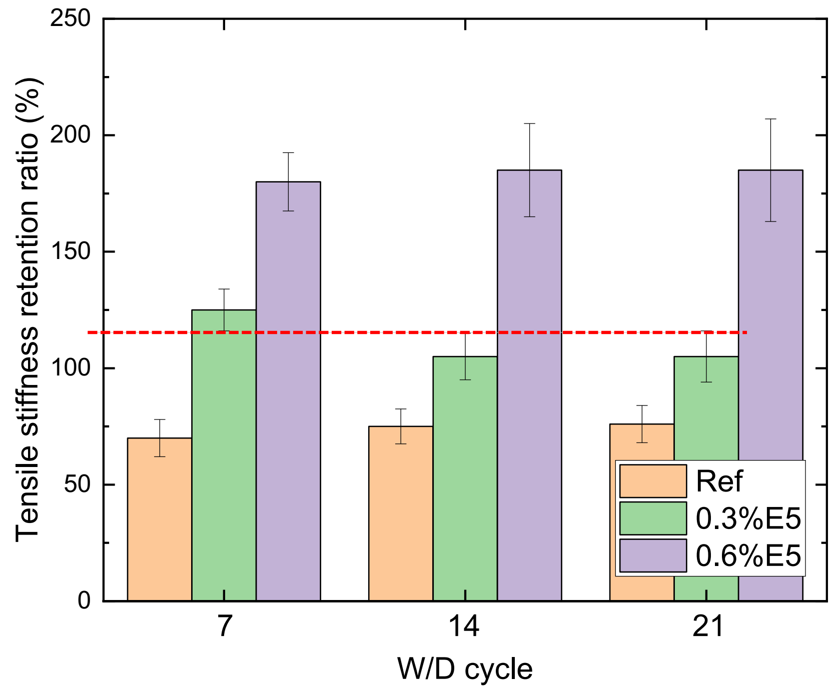
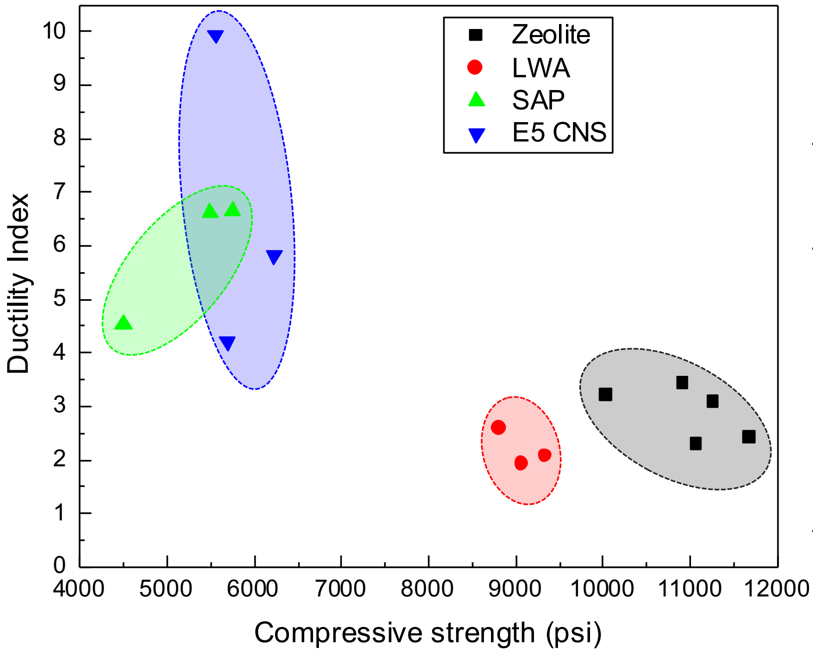
Tensile Strength Recovery Results





- The tensile strength retention ratio of nano silica based SHCC (0.6%) reached 100% or above.

Ductility Performance



Mix	W/C	Fly Ash (% cement wt.)	Slag (% cement wt.)	PVA Fiber (volume)
Zeolite SHCC	0.35	0.15	0.15	2%
LWA SHCC	0.35	0.15	0.15	2%
SAP SHCC	0.35	0.15	0.15	2%
E5 CNS SHCC (w/ VMA)	0.35	0.50	0	1%

- All the SHCC mix presented strain-hardening behavior with the ductility index greater than 1.
- E5 CNS SHCC shown highest ductility due to the incorporation of VMA and nano silica which optimized interfacial properties between fiber and matrix even the fiber volume is lower than other sets.

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Low Carbon, High Performance Concrete in Indiana

- I-469 in Allen County, IN
- Low shrinkage crack
- Reduced cement usage by 90 lbs/CY of concrete, 15% of cementitious materials
- Reduced 400 gallon of water usages
- 30,000 lbs of CO_2 reduction, equivalent to 100 cars off-road for a week
- Reduced materials cost $25 per cubic yard of concrete

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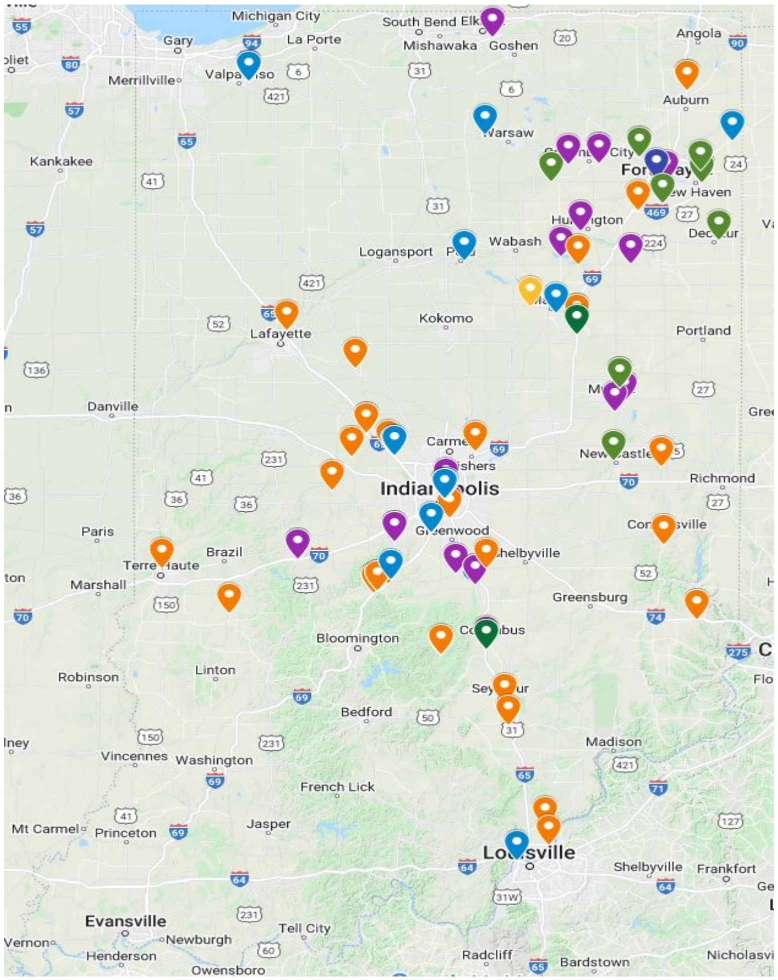
Low Carbon, High Performance Concrete in Indiana



- 120 Bridge Deck Pour
- 22 Pavement Project

Broad participation

- 16 different contractors
- 8 different ready-mix companies
- Allen & Whitley Counties
- Purdue University, West Lafayette IN

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Using cost-effective sensors for assets management and prevention

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When should we open the traffic?

Requirement for Determining Early-Age Concrete Strength

Curing time &
open to traffic

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The Challenge

Construction Scheduling → Construction and Maintenance

- Open too early cause pre-mature failure and frequent patching

- Construction delay causing traffic jam

Requirement for Determining In-situ Concrete Strength

https://lacrossetribune.com/news/local/traffic-jam/

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Conventional Strength Testing

Current Methods

- Compression/ cylinder break
- Flexural/ beam break

Disadvantages

- Up to 50% error
- Time consuming
- Requires skilled labor
- The actual in-place concrete is not being tested

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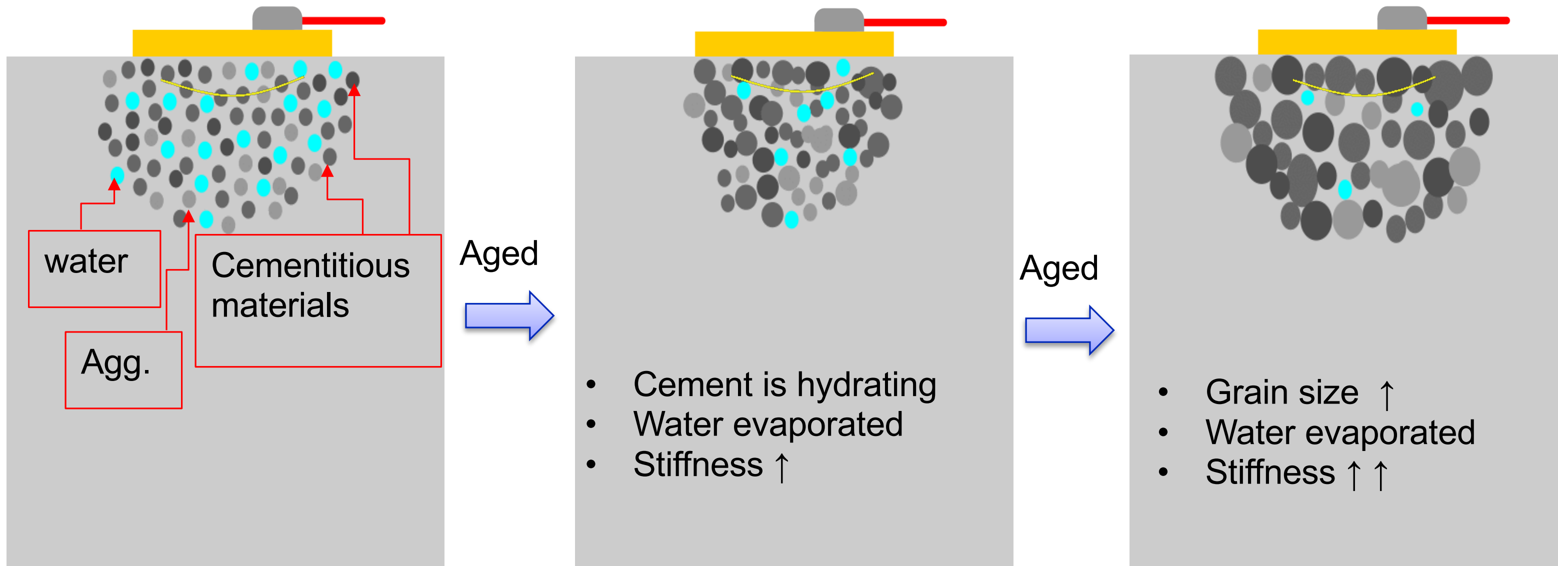
Piezo-sensor for Concrete Strength Monitoring



Using piezoelectric sensor to understand the concrete stiffness and strength through electromechanical coupling effect.

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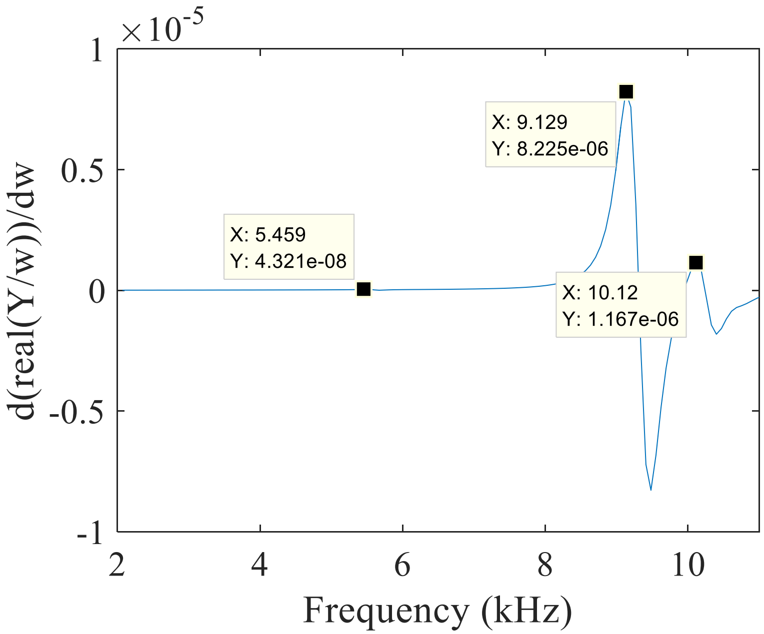
Mathematical Principle of Sensing Methods

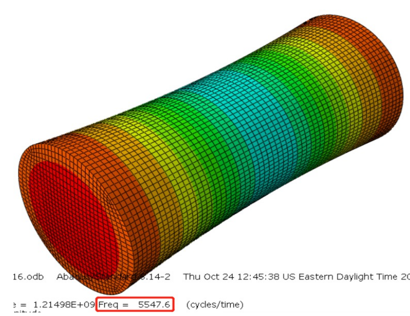
A mathematical computation of mechanical properties of concrete using piezoelectric sensors and vibration resonance

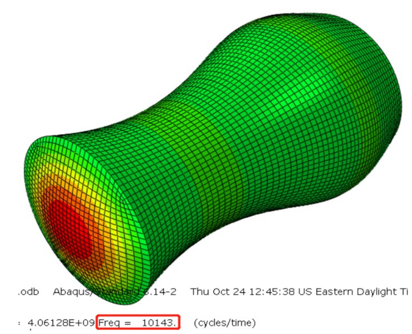


$$E_d = (f_r \cdot g)^2 \cdot \rho \cdot \frac{(1+\mu)(1-2\mu)}{1-\mu} \cdot 10^{-9}$$

$$E_s = 0.65 \cdot {E_d}^{1.04}$$

$$f_c' = \left(E_s \cdot \frac{10^3}{0.043 \cdot \rho^{1.5}}\right)^2$$





Z. Kong et. al *<u>Journal of Aerospace Engineering</u>, 33, 04020079, 2020*

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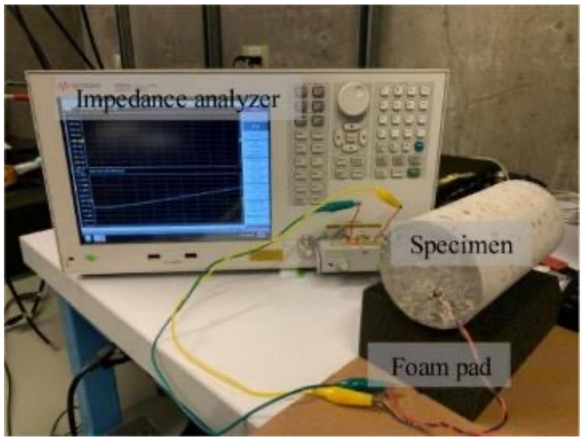
Compression Testing Comparison

No pre-developed database is needed, direct measurement



Modulus	6024 psi		Modulus	5981psi
Strength	8847 psi		Strength	8784 psi

- Sensing and compressive testing conducted on the exactly same cylinder
- Modulus and Strength results are identical

Z. Kong et. al Journal of Aerospace Engineering, 33, 04020079, 2020

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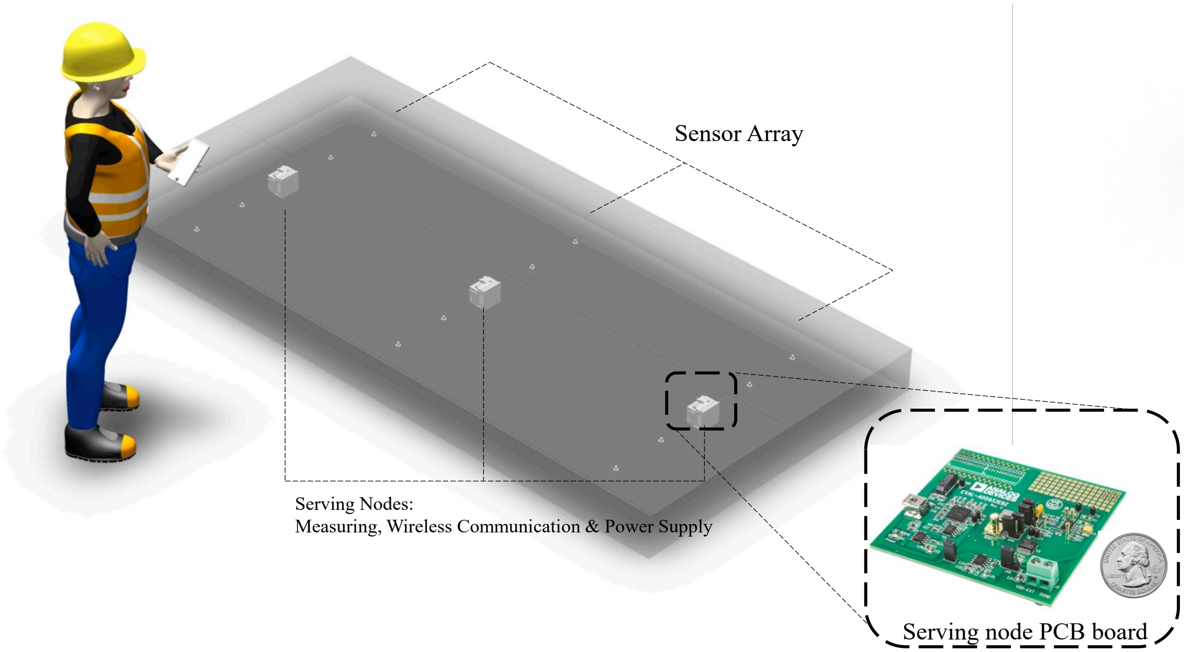
IoT sensing Platform

- Wireless transfer of concrete pavement strength information on any projects
- Reduce construction time/cost by 30%, and reduce insurance rates by 25%



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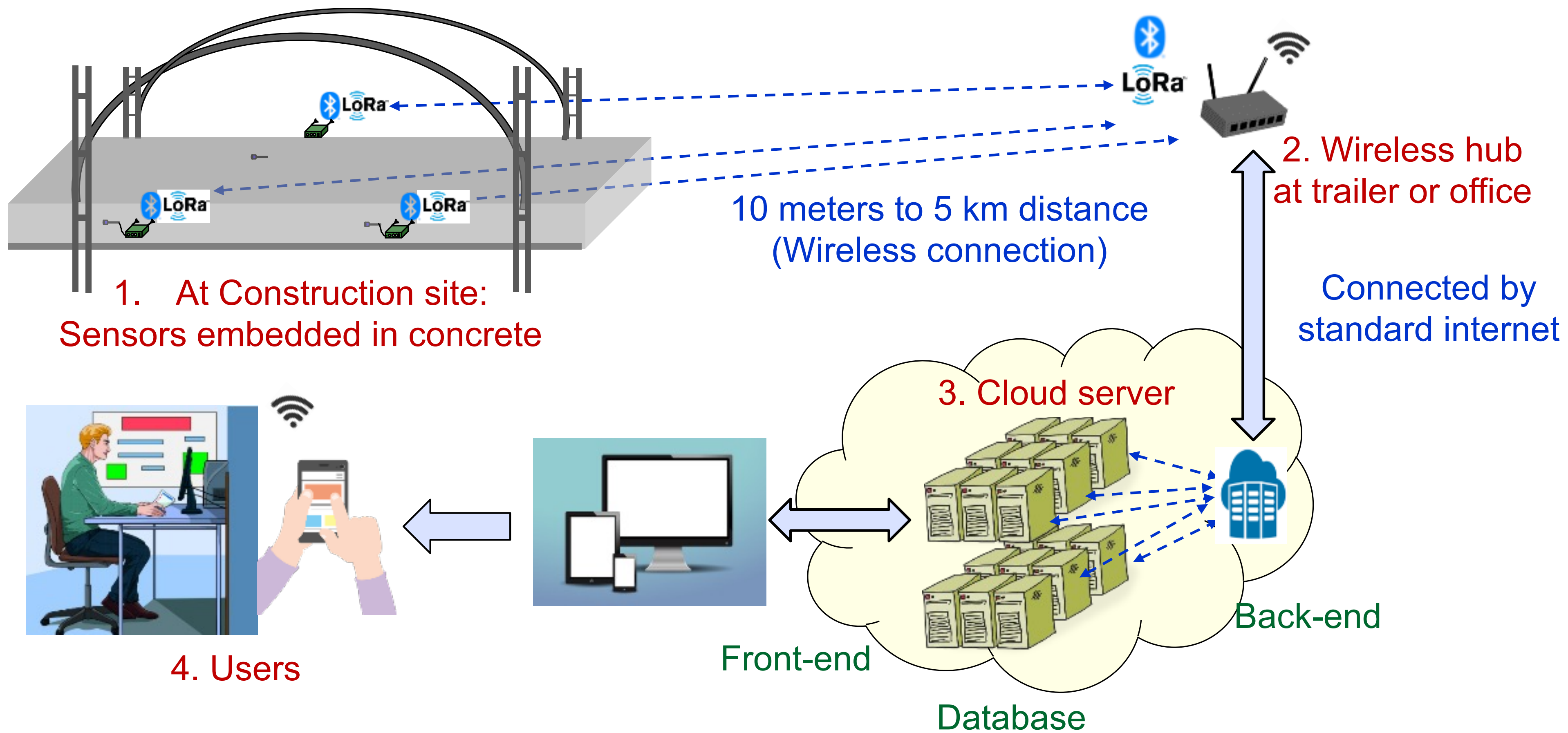
IoT sensing Platform



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Value Proposition

Increase concrete productivity by 30%+

Reduce construction time & associated cost by 30%+

Reduce cement usage by 20%+ (and resulting carbon emissions)

Reduce insurance rates by 20%+

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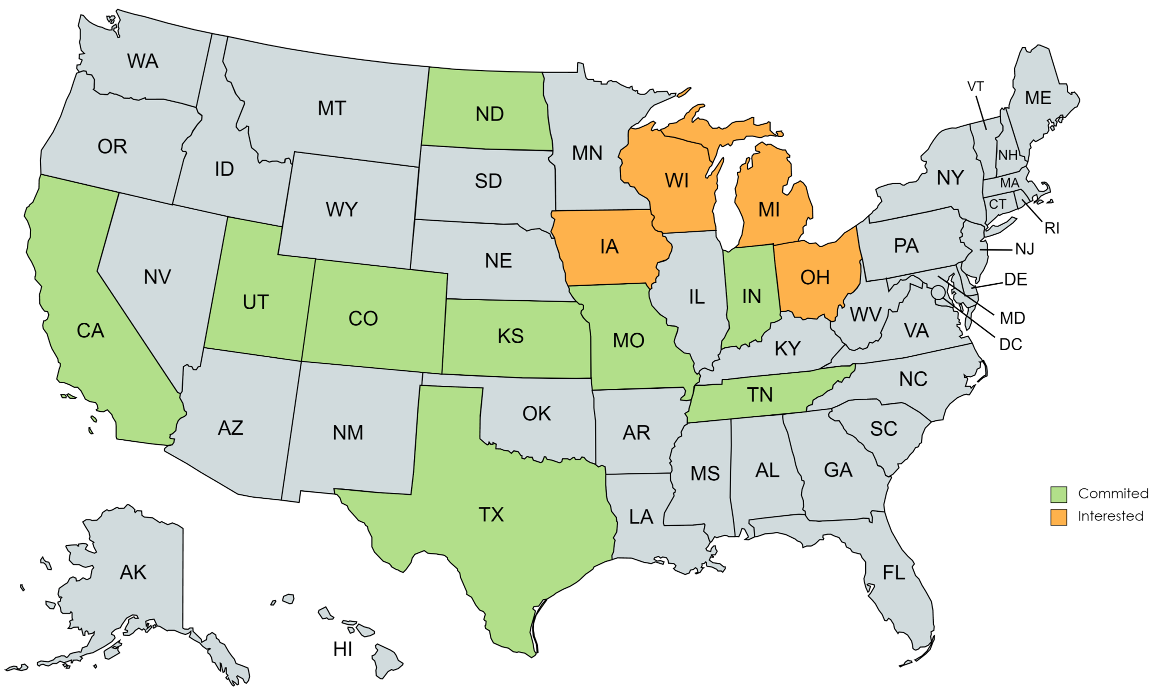
FHWA Pooled Fund Study – 1499



Committed states

- Caltrans
- Colorado DOT
- Indiana DOT
- North Dakoda DOT
- Missouri DOT
- Texas DOT
- Tennessee DOT
- Kansas DOT
- Utah DOT

New AASHTO Standard

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Nationwide Field Testing


Garrett, IN


Tennessee


Missouri


Indy


Kansas


Colorado

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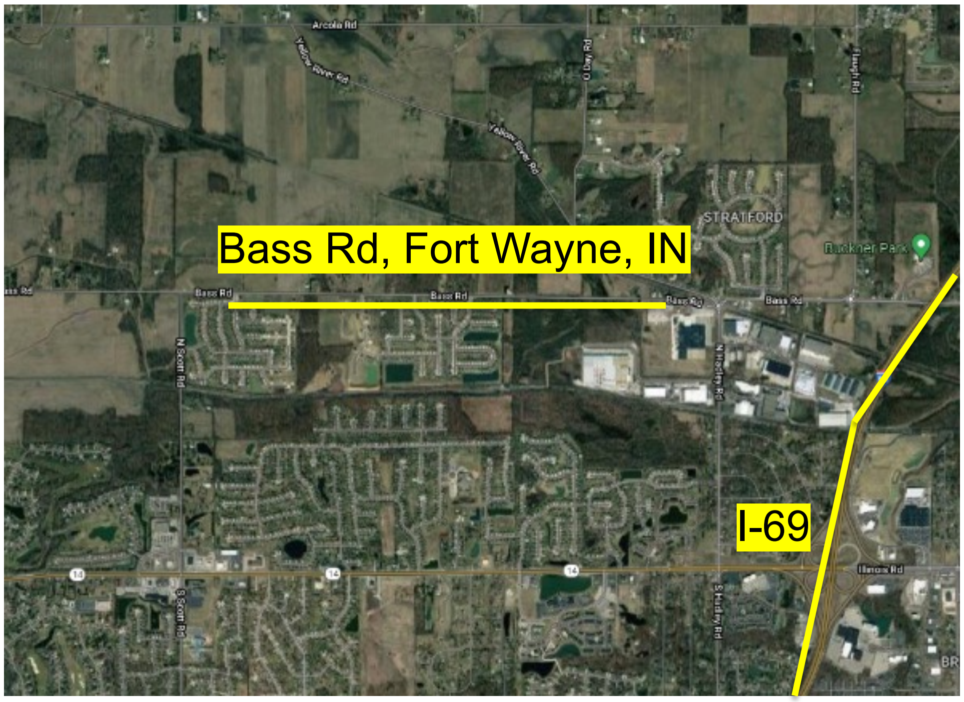
Full Depth Paving – Fort Wayne



Contractor: Primco Construction, Sept-02-2021
Slab Thickness: 12”
Mix: w/c= 0.42, 6 oz E5 nano-silica incorporation

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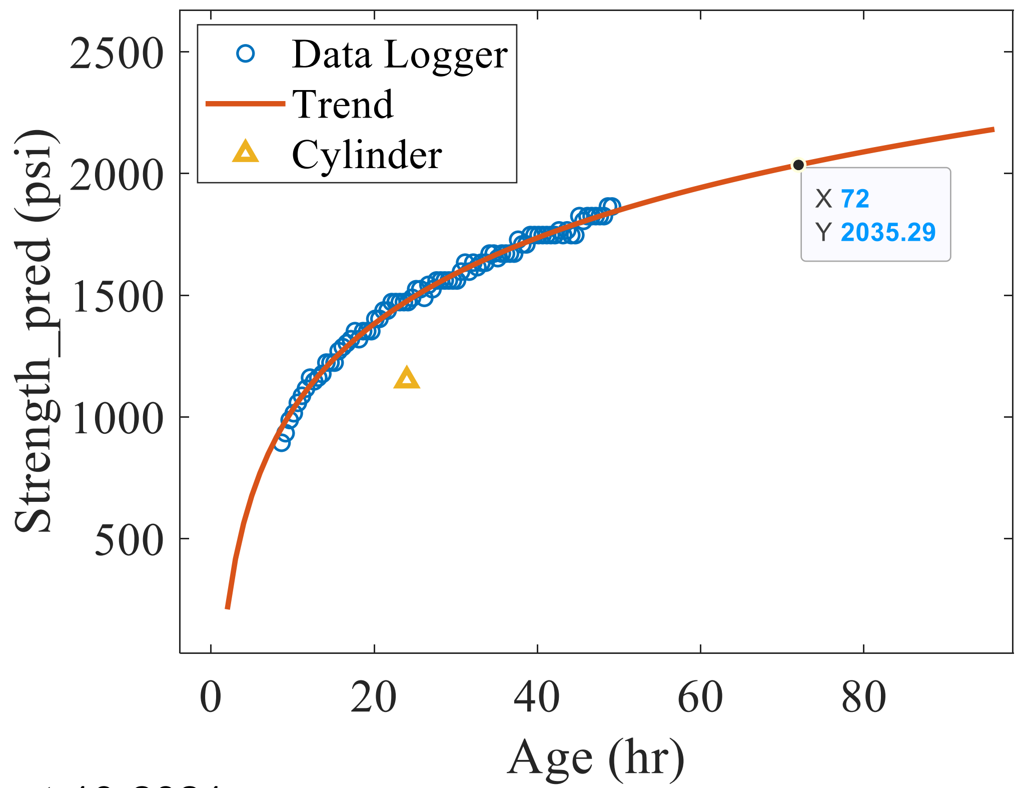
Indianapolis International Airport Project



Concrete Contractor: Milestone Construction; Sept-10-2021
Slab Thickness: 18”
Mix design: w/c= 0.43 with 40% slag for ASR

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Indiana I-69 Paving

Date	2023-7-25
Location	Indianapolis, IN
Coordinate	39.691282, -86.204355
Pavement Thickness	11''
Rebar	#6 (0.75'')

Ingredients	**Amount (/yd^3)**
Fine Agg.	1268 lbs
Coarse Agg.	1830 lbs
Type IL	425 lbs
Slag	145 lbs
Water	233.7 lbs
W-C-Ratio	0.410

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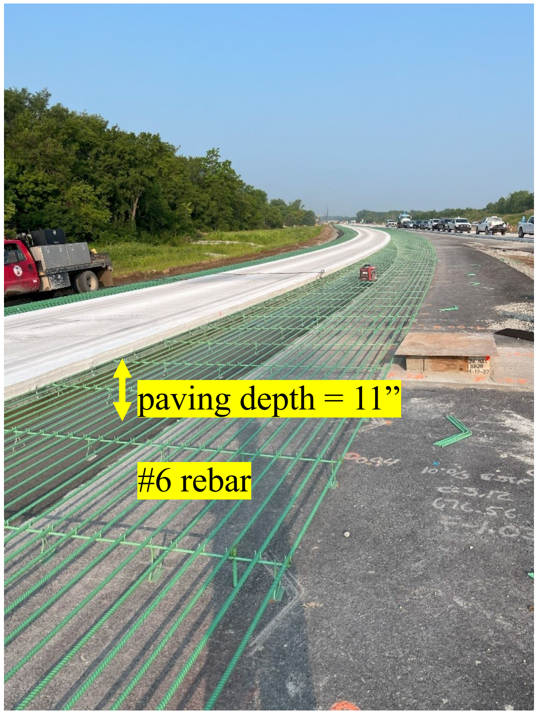
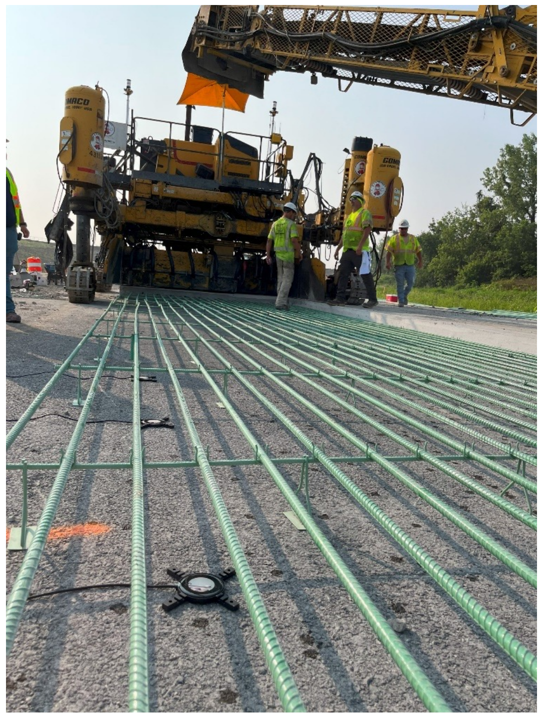
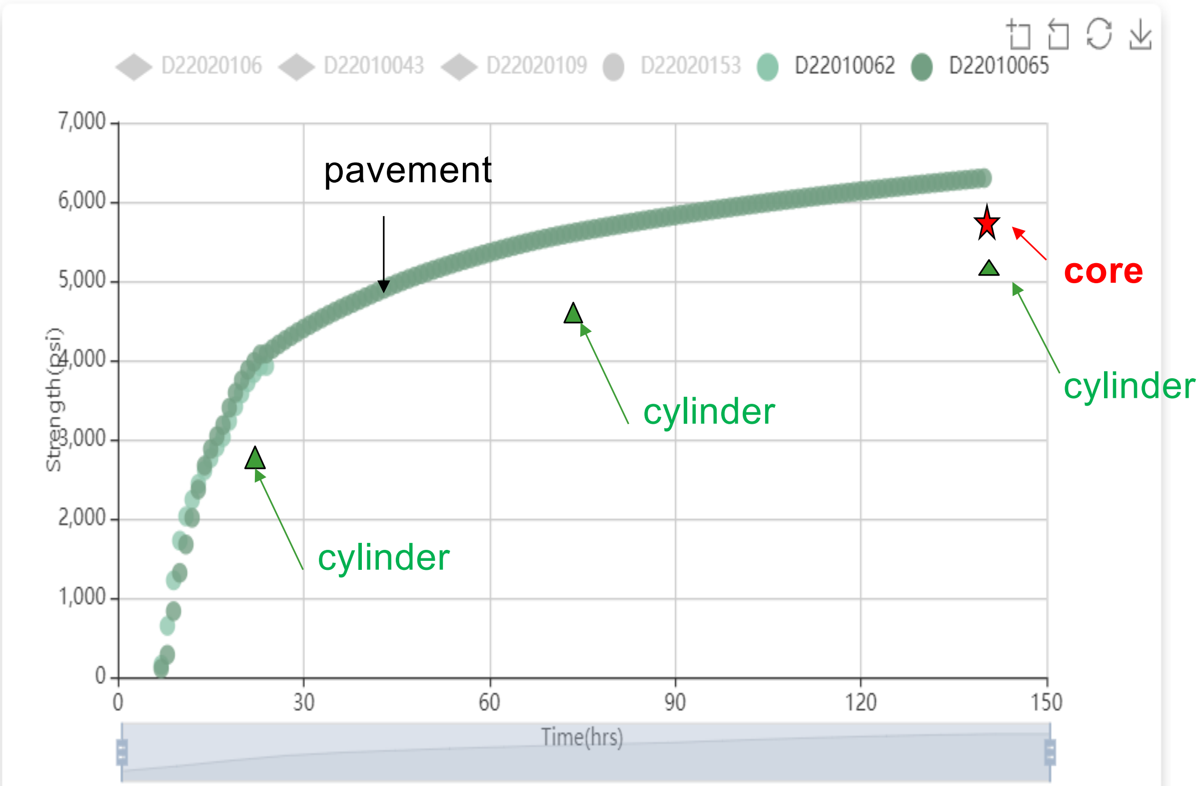
Indiana I-69 Paving





Indiana I-69 Paving

Sensing Results vs Cylinder Results



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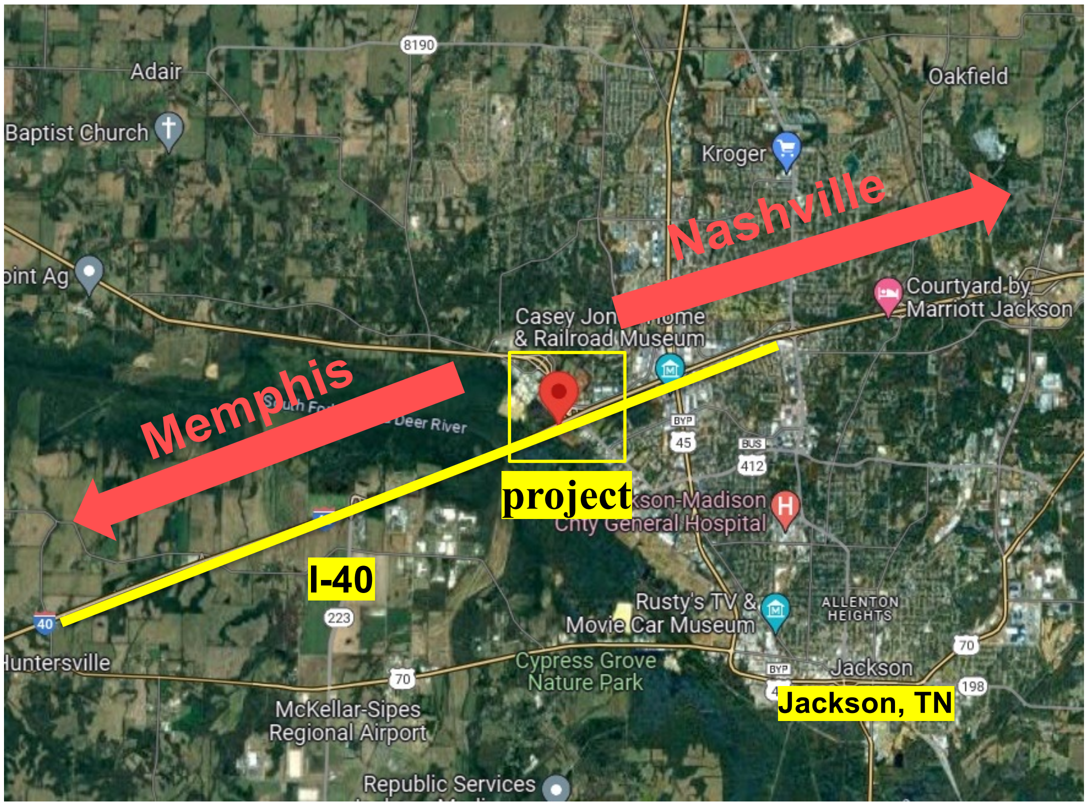
Tennessee I-40 Bridge Pavement & Parapet Wall



Date	7-12-2023
Location	Jackson, TN
Coordinate	35°39'20.2"N 88°52'40.9"W
Wall Depth	4.5 ft

Mixture	**Amount (/yd^3)**
Fine Agg.	1214 lbs
Coarse Agg.	1800 lbs
Cement	423 lbs
Fly Ash	141 lbs
Water	254.5 lbs
W-C-Ratio	0.430

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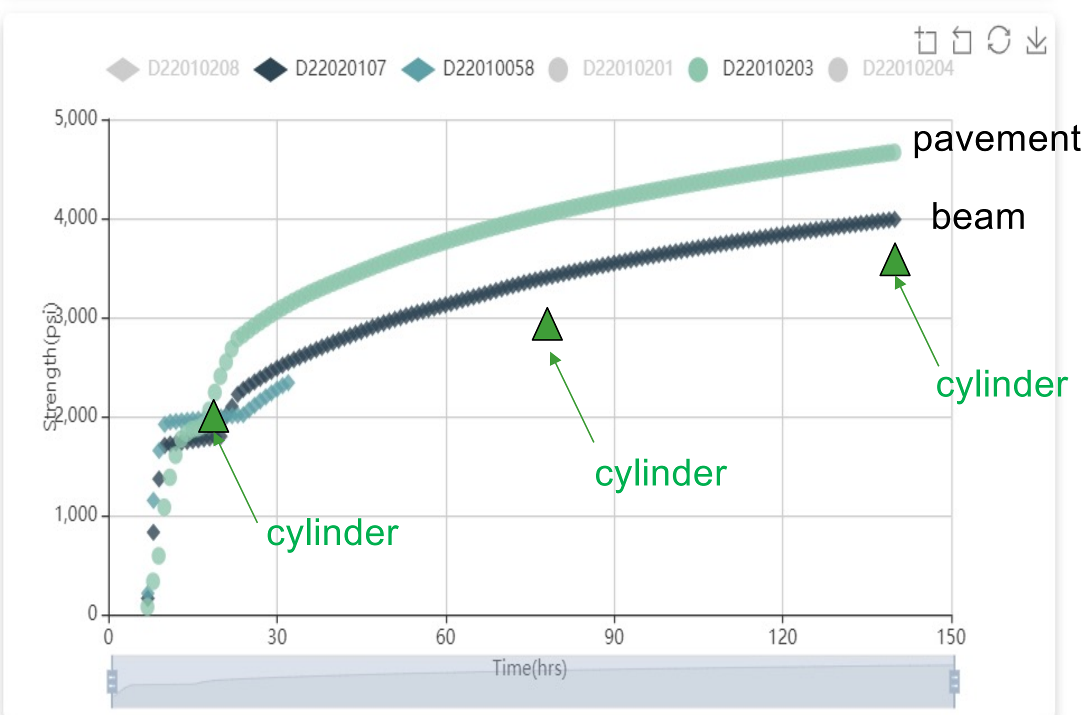
Tennessee I-40 Paving

Sensing Results vs Cylinder Results



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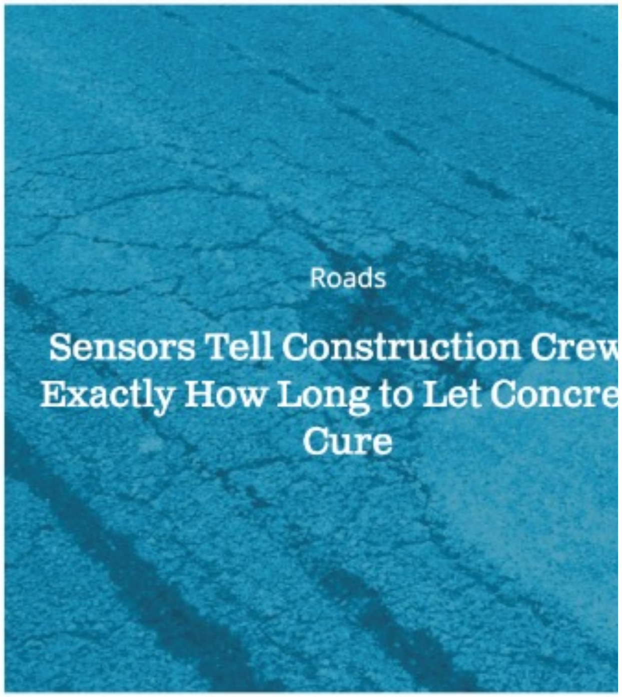
ASCE Game Changer

2021
REPORT CARD
FOR AMERICA'S INFRASTRUCTURE



PurdueTODAY

150 YEARS OF GIANT LEAPS

August 29, 2019 | Current web edition

IN THE SPOTLIGHT

Science to reveal how long highway construction should actually take

Ever wonder why your commute or vacation route has a lane closed down for days or even months at a time? It could be because a construction project wrapped up before the concrete was ready to take on heavy truck traffic, causing the pavement to fail too soon and need repairs more frequently throughout the year. Indiana, the "Crossroads of America," is doing something about it: Asking researchers to find out exactly how long it takes for concrete to mature on a highway.

August 29, 2019

aci Concrete SmartBrief

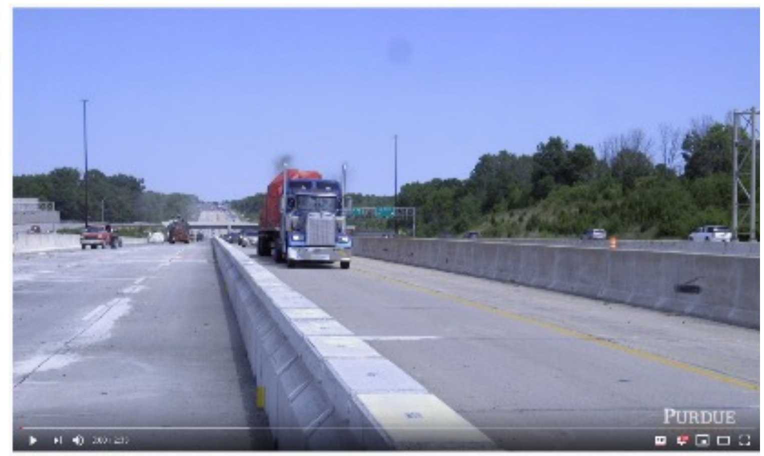
News for and about concrete professionals | SIGN UP · FORWARD

INDUSTRY NEWS

Purdue engineers collecting data on concrete maturity for INDOT

Engineers at Purdue University have designed sensors that are being used to monitor real-time concrete strength development through factors such as hydration, stiffness and compressive strength. The Indiana Department of Transportation plans to adopt the sensors on highways to keep contractors informed on concrete distress.

EurekAlert!/Purdue University (8/29)



Piezoelectric Sensor for Measuring Concrete Strength

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US 30- Intelligent Highway Testbed

- Collaborating with Greater Fort Wayne and City of South Bend
- Building a 100 Miles intelligent Highway Testbed in Northern Indiana
  - Economic Development
  - Job Placement
  - Logistics
  - Healthcare
  - Energy Independence

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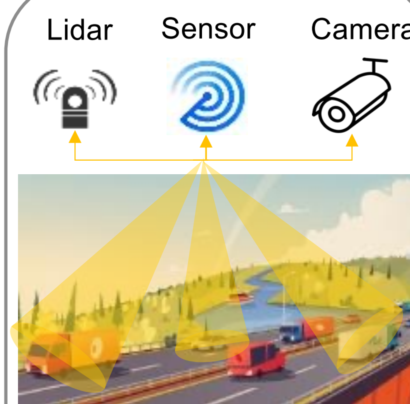
US 30- Intelligent Highway Testbed

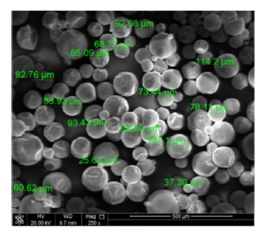
Intelligent Infrastructure

- Safety
- Mobility
- Sustainability
- Security

AI/Quantum- Guided Traffic Management



Data Acquisition



Sustainable Materials

Broadband Communications

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Smart Intersections

- Advanced sensors (camera, radar, Lidar) to monitor real-time traffic conditions
- Communication equipment to enable vehicle-to-infrastructure information exchange
- Cloud and/or Edge computing devices to support multi-modality data processing and decision making

Intelligent traffic signal control: Provide priority to transit and emergency vehicles and improve overall mobility

Cybersecurity: detect abnormal vehicle/traffic behaviors and protect the system from cyberattacks

User (VRU) Protection: predict conflicts between VRUs and vehicles to improve safety

Cooperative perception strengthen the situation awareness of autonomous vehicles and facilitate navigation

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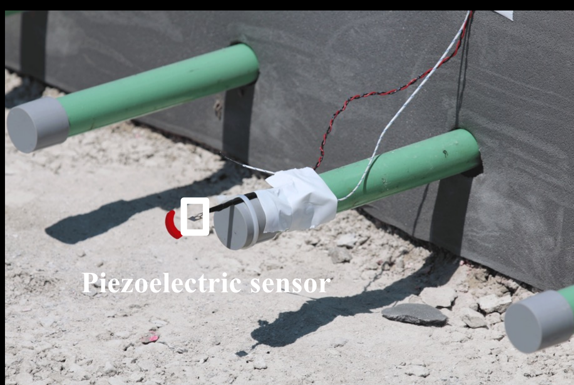
Intelligent Infrastructure Innovations



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