Long-Term Monitoring Technologies for the Monitoring of State Roads and Bridges

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Michigan Transportation Network

- Michigan plays a vital role in the national economy:
  - In 2009, $389 billion in goods are shipped out of Michigan
  - Another $407 billion in goods are shipped into the state
  - By 2020, estimated 50% increase in commercial trucking traffic

Problem: In coming years, we will be required to do more with less

Solution: *Innovative solutions are direly needed* to maintain an aging road and bridge system in the face of inadequate levels of funding

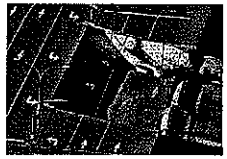
  - 25% of state bridges rated as "structurally deficient" or "obsolete"
- Perfect storm has emerged nationally in the U.S.:
  - Aging infrastructure translates into mounting maintenance costs
  - Reduction is availability of funding (federal, state, local)
  - ASCE estimates state requires $5.1 billion annually (2x current level)

What is at Stake?

Human Factor: I-35W Bridge
August 1, 2007

Triggers: Schoharie Creek Bridge
April 5, 1987

Deterioration: I-95 Overpass Collapse
June 28, 1983



Deterioration: de la Concorde Overpass
September 30, 2006

Much More than Bridge Failures

Cost-competitiveness: Aging infrastructure will require increasing resources moving forward

Resiliency: resiliency of community to natural hazards vital to economic recovery

Sustainability: Concrete is inherently brittle; 2 metric tons per person per year

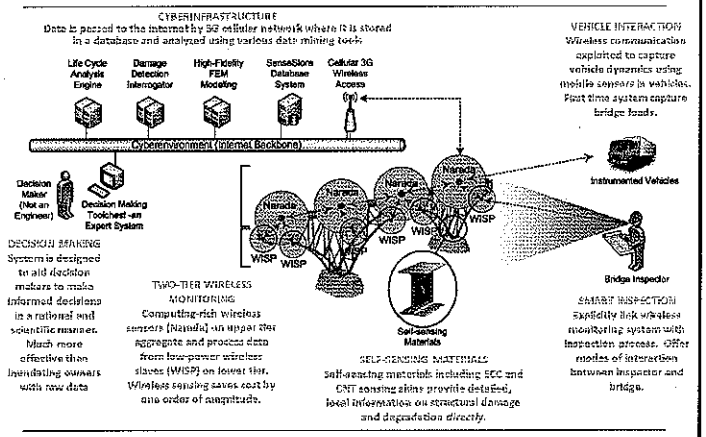
Sustainability: about 40% of life cycle energy related to repeated deck repairs

NIST Technology Innovation Program

- **National Institute of Standards and Technology (NIST) Technology Innovation Program (TIP):**
  - 5-year project focused on advancing SHM systems for bridges
  - Address the limitations of existing SHM systems
- **Comprehensive re-design of bridge SHM systems:**
  - Based on wireless telemetry as a core building block of the system
  - Researchers have emphasized sensors aimed at getting better data
  - We are focused on getting end-users "information," not just "data"

University of Michigan (LEAD) | Industrial Partners | Government Partners

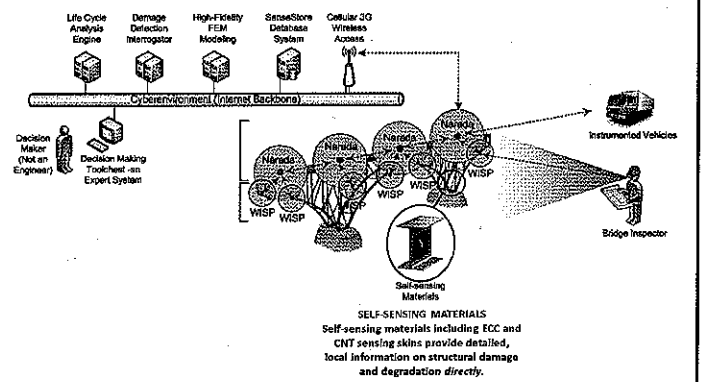
NIST TIP Project Overview



Who is our "Customer"?

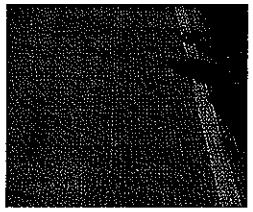
- **Major bridge owners with significant bridge inventories:**
  - *Michigan:* More than 10,000 bridges with an average age of 41 years
  - Other state DOTs would also be beneficiaries of key technologies
- **Desired benefits of structural health monitoring (SHM):**
  - Overall risk reduction of their asset inventories
  - Increased public safety and public confidence
  - Discovery of structural reserves after construction
  - Early detection of deterioration and defects = cost effective upkeep
  - Extended service lives = greater amortization of initial cost and energy

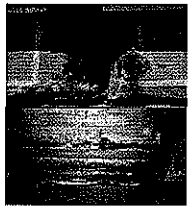
NIST TIP Project Overview



Motivation for New Materials

- **Concrete is susceptible to deterioration and damage:**
  - Concrete's brittle nature results in cracking and fracture:
    - More than 100,000 bridges in the U.S. have early age cracks
  - Corrosion of underlying steel:
    - $8.3 billion/yr are spent to directly address corrosion in American highway bridges; indirect cost can be many times of direct cost





Steel Reinforcement Corrosion & Concrete Cover Spalling

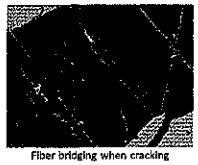
Below Deck Steel Girder Corrosion

Next Generation Concrete: ECC

- **New generation of cement-based materials:**
  - Include small polymeric fibers in the cement to make it ductile
  - Bends like a metallic material
  - Highly damage tolerant by dissipating energy through micro-cracks
  - Nano-engineered fiber-cement interfaces
- **Engineered Cementitious Composites (ECC) by Li:**
  - Utilized on a trial basis by the MDOT

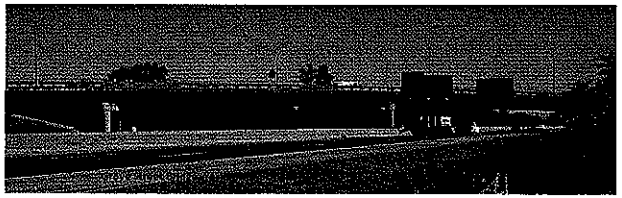
High ductility

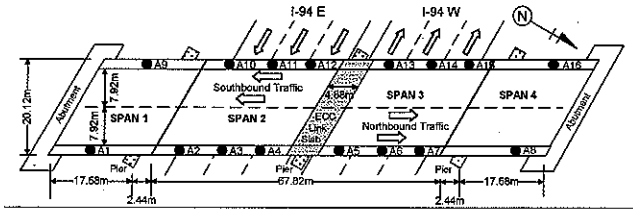
High damage tolerance



Fiber bridging when cracking

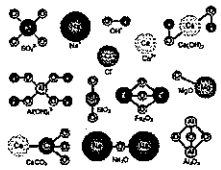
ECC Link Slab Technology





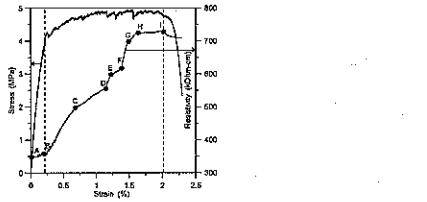
Self-Sensing ECC

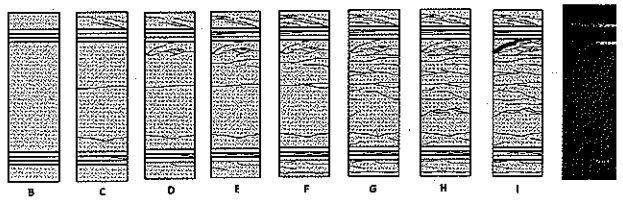
- **Cementitious materials eventually produce cracks:**
  - Observing and detecting cracks critical to managing bridge health
  - No sensor technology exists for sensing cracks in cement materials
- **ECC is a self-sensing cementitious material:**
  - Semi-conductor capable of transmitting electricity
  - We can correlate changes in electrical properties to strain and cracks



Ions in pore water

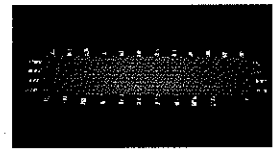
Electrical Properties of ECC

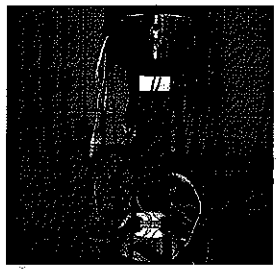




Tomographic Mapping of Damage

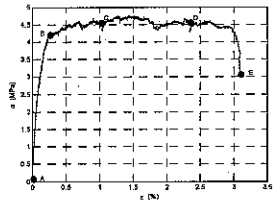
- **Use tomography to image cracking in ECC elements:**
  - Same concept as that used in CAT scans, MRIs and modern X-rays
  - Think of it like an "X-ray" of the structure showing its damage!

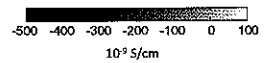


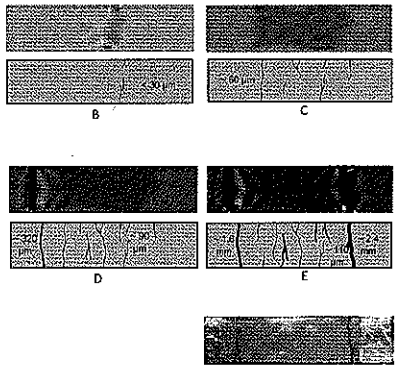


Specimen #	Type	Fiber used	Loading
1	Plate	1.5% (volume fraction) PVA	Tension
2	Plate	1.5% PVA	Tension
3	Plate	1.5% PVA + 0.1% Steel	Tension
4	Plate	1.5% PVA + 0.1% Steel	Tension
5	Plate	1.5% PVA + 0.4% Carbon	Tension

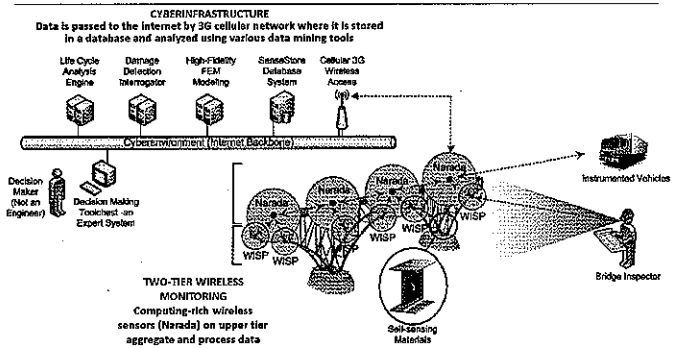
Tomographic Mapping of Damage







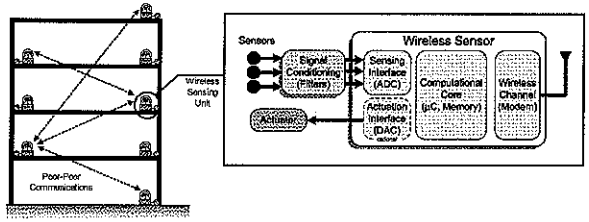
NIST TIP Project Overview



TWO-TIER WIRELESS MONITORING
Computing-rich wireless sensors (Narada) on upper tier aggregate and process data from low-power wireless slaves (WISP) on lower tier. Wireless sensing saves cost by one order of magnitude.

Wireless Structural Monitoring

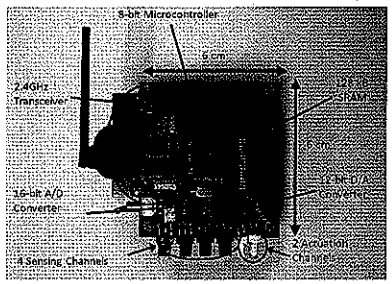
- **Wireless sensor networks are today viable substitutes:**
  - System constructed from low-cost wireless sensors (~$100 per node)
  - Low cost drives *high-density installation* targeting local damage
  - Computational power is coupled with sensors for data interrogation



Architectural design of wireless structural monitoring systems

Narada Wireless Sensor

- **Wireless sensor for SHM application (Swartz et al. 2005):**
  - 16-bit ADC resolution on 4 channels capable of high rates (100 kHz)
  - IEEE802.15.4 radio offers interoperability with other sensors
  - Rich embedded processor for sensor-based data interrogation



SPECIFICATIONS	
Cost	$175 per unit
Form Factor	5 cm x 6 cm x 2 cm
Energy Source	3 AA Batteries
Active Power	200 mW
Sleep Power	20 mW
Range	100 m
Data Rate	250 Kbps
Sample Rate	100 kHz

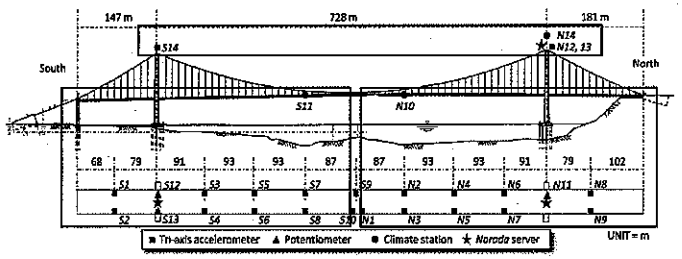
New Carquinez Bridge

- **New Carquinez Bridge (constructed 2003):**
  - Located in the San Francisco Bay Area (Vallejo, CA)
  - Total bridge length is 1056 m (main span of 728 m)
  - Main deck consists of steel orthotropic box girders
  - Hollow concrete tower legs and pre-stressed link beam

New Carquinez Bridge, California

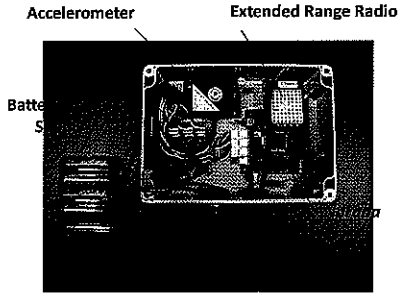
Phase 1 Instrumentation

- **28 wireless sensor nodes collecting 81 channels:**
  - 19 tri-axial accelerometers measuring main deck
  - 3 tri-axial accelerometers measuring vibrations at tower top
  - Wind vane, anemometer and temperature in three locations
  - 3 string potentiometers to measure deck movement relative to tower



Packaged *Narada* Units

- **Packaging for long-term deployment on NCB:**
  - Water tight enclosure for all electronics
  - Magnetic mounting for quick and easy installations



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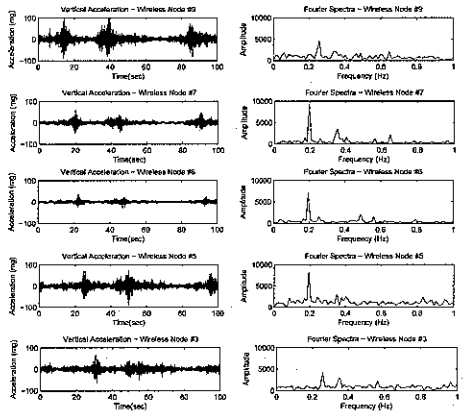
Ambient Vibrations



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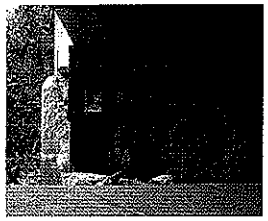
Telegraph Road Bridge (TRB)

- **Constructed 1973 in Monroe, MI:**
  - Cantilever bridge
  - Steel girders
  - Pin & hanger construction
- **Serious deterioration encountered:**
  - Deck cracking
  - Corrosion of steel girders
  - Failure of bridge abutment structures
  - Fatigue failure



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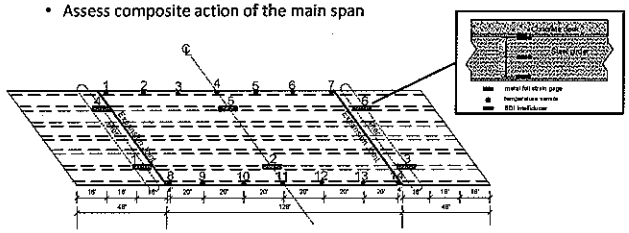
Sensor Instrumentation

- **Permanent wireless monitoring system consisting of 32 channel recorded with 20 *Narada* wireless sensor nodes:**
  - 14 accelerometers integrated to 14 *Narada* wireless nodes (Oct 2011):
    - Measure main span response to truck loads
  - 18 strain gages installed in 6 locations using 6 *Naradas* (April 2012):
    - Each location has three strain gages measuring girder response
    - Assess composite action of the main span



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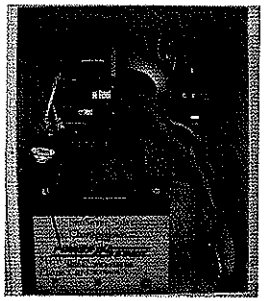
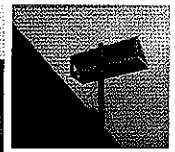
Communication Base Station

- **Installed May 2011:**
  - Successfully established reliable communication with sensor nodes and University of Michigan server



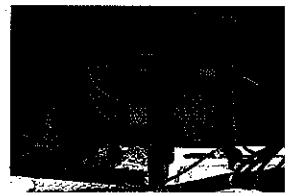
TRB Server with 3G Cell Connection

MDOT Assisted Installation



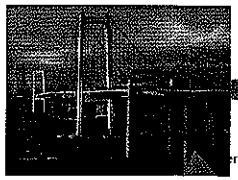
Final Product

Sensor Instrumentation



"Big" Data

- **Sensor technologies now make massive amounts of data available to us today:**
  - New Carquinez Bridge is a classic example
  - How does bridge owner manage the data?
    - Definitely will not be manual
    - Automation of data management and data processing



How Big is the Data?

- 80 channels on NCB
- Collect once every 4 hours
- 11.5 million data points a day
- 4.2 billion data points a year
- 8.5 GB of data per year

orbital "double-edge" sword

Cyberinfrastructure Solution

Handle Data Autonomously, Efficiently, & Robustly

- Scalable Data Storage
- Automated Data Analysis
- Secure Data Access

Lower Tier	Higher Tier	
Smart Structures	**Middleware *SenStore***	**Data Processing Tools**
• Collect Data On-demand	• Scalable Data Storage • Secure Data Access Management	• Use Shared Data • Automated Data Analysis

Summary

- **Powerful new technologies proposed for SHM systems:**
  - Exotic new cement-based materials means more durability
  - Ultra low-power wireless sensors with embedded data processing
  - Powerful cyberenvironment for asset managers for data mining
- **Validation of all monitoring technologies underway:**
  - New Carquinez Bridge has been an invaluable testbed for validation
  - Telegraph Road Bridge also being instrumented
- **Role of University of Michigan in state transportation:**
  - Recognized technology leader in sustainable cementitious materials
  - Key driver in structural health monitoring of roads and bridges
  - Close partnership with MDOT
  - Eager partner with policy makers to shape state transportation policy

Thank You!

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