Wireless Sensor Monitoring of Structures During Extreme Events

Passive Wireless Sensor Technology Workshop
June 2012

Fred Faridazar

The Office of Research, Development, and Technology (RD&T)
Turner-Fairbank Highway Research Center (TFHRC)
McLean, VA
Outline

- Exploratory Advanced Research
- Infrastructure
- Seismic Vulnerability Assessment of National High Priority Corridors
- Operations
- Safety
Federal Highway Administration Headquarters Offices

• Office of Administration
• Office of Chief Counsel
• Office of the Chief Financial Officer
• Office of Civil Rights
• Office of Federal Lands Highway
• Office of Infrastructure
• Office of Innovative Program Delivery
• Office of Operations
• Office of Planning, Environment, and Realty
• Office of Policy and Governmental Affairs
• Office of Professional and Corporate Development
• Office of Public Affairs
• Office of Research, Development, and Technology
• Office of Safety
Turner–Fairbank Highway Research Center
Research and Development Programs
http://www.fhwa.dot.gov/research/tfhrc/programs/

Exploratory Advanced Research
Infrastructure
Operations
Safety
Announcements
FHWA EAR Program Initiates Two Studies in Foundational Research for New Approaches to a National Transportation Demand Model

EAR Program Participates in an NSF Study on Underground Geo-engineering

FHWA EAR Program Workshop Explores Technological Innovations in Transportation for People with Disabilities

Highlighted Activities
Research on the Future

FHWA EAR Program Partners on Cyber-Physical Systems

FHWA EAR Program Investigates Nano-scale Approaches for Highway Research
Exploratory Advanced Research (EAR) Program

Expert Review

• Support from over 200 experts
  – Topic generation and scoping
  – Evaluation of proposals, ongoing research
• Building expert networks
• Anticipating emerging areas
Exploratory Advanced Research (EAR) Program

Program Status

• 80+ Initial stage investigations
  – Nanoscale research workshop
  – Smart Particles RFI

• Five solicitations resulting in
  – 39 projects awarded
  – $29M federal, $15M match
  – More projects under review
Potential Breakthroughs

• New research methods
  – Driver engagement (GM)
  – Behavioral economics (UCF)

• New models
  – Driver visibility (SAIC, TTI, NIST, Virginia Tech)

• New technology
  – Scour measurements (TFHRC, ANL, NASA JPL)
Exploratory Advanced Research (EAR) Program

Topics under Investigation

• Integrated Highway System Concepts
  – International approaches: vehicle automation
• Nano-scale Research
  – Measurement of dispersion
• Human Behavior and Travel Choices
  – Dynamic ridesharing
  – Vision assisted technologies
• Energy and Resource Conservation
  – Sustainable underground structures
  – Electric vehicle commercialization
Exploratory Advanced Research (EAR) Program

Topics continued

• Information Sciences
  – Video decoding, feature extraction
  – Probabilistic record linkage (data mining)

• Breakthroughs in Materials Science
  – “Self-healing” materials
  – Cement hydration kinetics

• Technology for Assessing Performance
  – “Smart balls” for autonomous culvert inspection
  – Pressure sensitive paints for aerodynamic testing;
  – Remote sensing for environmental processes
Exploratory Advanced Research (EAR) Program

EAR Program website
www.fhwa.dot.gov/advancedresearch

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Federal Business Opportunities
FedBizOpps.GOV
Turner–Fairbank Highway Research Center
Research and Development Programs
http://www.fhwa.dot.gov/research/tfhrc/programs/

Exploratory Advanced Research
Infrastructure
Operations
Safety
Office of Infrastructure R & D

Infrastructure

- Pavement Materials
- Pavement Design and Construction
- Long Term Pavement Performance
- Bridge and Foundation Engineering
- Hazard Mitigation
- Infrastructure Management
Office of Infrastructure R & D
Infrastructure

- Pavement Design and Construction
- Hazard Mitigation
- Bridge and Foundation Engineering
HMA from Plant

Haul Truck

Paver

The Solution?

Encapsulated RFID Tag

Tags scanned when convenient after construction

Vehicle with RFID Reader and GPS

Compaction

Finished Pavement
Tracking: The Problem
Data Interpretation: Damage Estimation
Power Dissipation Scale

- $10^9 W$: Hoover Dam
- 745W: 1 Horse Power
- 170W: Intel Itanium Quad-core
- 100W: Metabolic rate of Human Body
- 80W: Intel Pentium 4
- 30W: Power consumption of human brain
- $10^{-2} W$: Laser in DVD ROM
- $10^{-3} W$: Texas Instruments MSP430
- $10^{-5} W$: Quartz wristwatch
- $10^{-9} W$: Air flow at 5m/s per sq mm
- $10^{-12} W$: Average power consumption of a human cell
- $10^{-18} W$: Thermal noise
- $10^{-21} W$: Power received by deep space antenna from Galileo probe

- $10^{-6} W$
Design of robust packaging system

1- Chemical + Mechanical protection : Epoxy layer

2- Thermal insulation: Polyurethane foam

3- Chemical + Mechanical protection: Epoxy layer

Antenna

Sensor

Wires connected to the piezo-transducer
Packaging and Installation

- Antenna
- Sensor
- Wires connected to the piezo-transducer
FHWA Field Study At the ALF

- 24 hours continuous testing: Sensor electronics and packaging survived the load.

- RFID and data collection interface needs to be more robust.
Envisioned monitoring system

Miner’s rule:

\[ \sum_{i=1}^{m} \frac{n_i}{N_i} = 1 \]
Office of Infrastructure R & D
Infrastructure

- Pavement Design and Construction
- Hazard Mitigation
- Bridge and Foundation Engineering
Hazard Mitigation Team

- Sheila Duwadi
  - Team Leader
  - Bridge security
  - Wood composites/timber bridges
  - Covered bridges
- Harold Bosch
  - Bridge aerodynamics
- Frank Jalinoos
  - Geophysics
  - Sensors & sensing systems
- Kornel Kerenyi
  - Bridge Hydraulics
- Eric Munley
  - Bridge security
  - Fiber reinforced plastic composites
- Fred Faridazar / Phil Yen
  - Seismic
Hazard Mitigation Team

Hydraulics

- Wave forces
- Drag & lift
- Computational analysis

Aerodynamics

- Bridge monitoring
- Bridge cable vibration tests
- Computational analysis
- Flow Visualization in a wind tunnel
Hazard Mitigation Team
Wave Forces on Bridge Decks – Hurricane Katrina 2005 (cont’d)
Hazard Mitigation Team
Commodore Barry Bridge – USA, 2000
Office of Infrastructure R & D
Infrastructure

- Pavement Design and Construction
- Hazard Mitigation
- Bridge and Foundation Engineering
Bridge and Foundation Engineering Team
Bridge and Foundation Engineering Team

Analysis of the Structure
I-35W Bridge Collapse Investigation
Bridge and Foundation Engineering Team

Recovery
Bridge and Foundation Engineering Team

NCHRP 12-84 Load Frame
Seismic Behavior of Curved Highway

University of Nevada, Reno
Hazard Mitigation Team

- Federal Highway Administration
- Network for Earthquake Engineering Simulation
- National Science Foundation
- Caltrans

PIs: Dr. Ian Buckle, Dr. Ahmad Itani, Dr. David Sanders

Research Students: Eric Monzon, Joe Wieser, Michael Levi, Danielle Smith, Hartanto Wibowono, Chunli Wei, Ahmad Saad, Nathan Harrison, Moustafa Al-Ani, and Dr. Arash Zhagi

Project Management: Kelly Lyttle
Seismic Behavior of Curved Highway Bridge

- Applications:
  - thermal expansion, shrinkage, misalignment or rotation, seismic, displacement and ambient vibration.
Ultra-High Performance Concretes (UHPC)
Seismic Behavior of Curved Highway Bridge

- Curved bridge with:
  - conventional bearing details
  - full isolation
  - hybrid protective systems

- Comparisons of:
  - bridge periods
  - bridge displacement
  - support shears
  - column performance
Curved Bridge: Full Isolation Case

Bridge with Monolithic Pier-to-Deck Connection
Column Damage at 150% DE

Pier 2
Conventional Case

Pier 2
Full Isolation Case

Pier 3
Conventional Case

Pier 3
Full Isolation Case
Curved Bridge: Full Isolation Case

- Lengthen the period
- Reduction in column forces
- Increased displacement

At Abutments
Hybrid Isolation (Partial Isolation)

Bridge with Monolithic Pier-to-Deck Connection

Bridge with Hybrid Isolation (Partial Isolation)

Hysteretic energy dissipator

Attract loads away from columns

Hysteretic energy dissipator
Note: These are resultant superstructure displacement at the center of the bridge (i.e. mid-span of Span 2).
Isolator Displacements

### Abutment 1

- **Displacement (in)**
  - Full_Isol
  - Hybrid

- **% Design EQ**
  - 0
  - 25
  - 50
  - 75
  - 100
  - 125
  - 150

### Abutment 4

- **Displacement (mm)**
  - Full_Isol
  - Hybrid

- **% Design EQ**
  - 0
  - 25
  - 50
  - 75
  - 100
  - 125
  - 150
Column Damage at 300% DE

Pier 2
Conventional Case

Pier 2
Full Isolation Case

Pier 3
Conventional Case

Pier 3
Full Isolation Case
Hazard Mitigation Team
Abutment Uplift: Conventional Case at 350% DE
Ultra-High Performance Concretes (UHPC)
Conclusions

• Full isolation is effective at keeping the columns elastic under the design earthquake and essentially elastic under the maximum considered earthquake.

• Hybrid isolation is also effective at keeping the columns elastic under the design earthquake and essentially elastic under the maximum considered earthquake.

• Hybrid isolation is effective at reducing the superstructure displacement.

• Hybrid isolation increases the shear force demand on the abutments.
Adaptive Bridge Bearing for Long-Term Bridge Performance

Magneto-Rheological Elastomers (MREs)
Composition/Manufacturing Process
- Ferrous Particles & Elastomers or Robber – Like Solid
  - Impose Magnetic Field –
    - Orient Particles to Chain Colum
Magneto-Rheological fluids (MRF):

Magneto-rheological fluids MRF):

**Operating principle**
Suspension of electrically polarizable particles in a non-conductive fluid
Particle alignment in an electric field
Rapid change of the viscosity characteristics of the fluid

http://www.cesma.de
Briefing on Seismic Vulnerability Assessment of National High Priority Corridors
OUTLINE

• Background and Objectives
  – Scope & Tools
  – Approaches/ Anticipated Results
• Progress
• REDARS and FAF programs Introductions
• Simulation Results
  – REDARS
  – FAF
• Milestones
• Comments/ Suggestions
Tools

• **REDARS** (Risks from Earthquake Damage to Roadway Systems) Version 2 -- Methodology and Software for Seismic Risk Analysis of Highway Systems

• **DYNASMART-P** is a state-of-the-art dynamic network traffic planning tool

• **FAF** (Freight Analysis Framework) Version 3 -- The FAF integrates data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation.
Approaches

- Using REDARS Program to perform earthquake damage/loss estimations in one of most possible scenarios
  - Direct Loss of Bridge/Highway Structures, including repairing cost
  - Travel Congestions/Time Increases.
  - Recovering Time/Resilience
- Using FAF to perform Data Analysis due to Bridge/Highway Structure Damages
  - Freight Route Interruption
  - Rerouting time and distance to estimate cost
Anticipated Results

• Cost estimate of transportation infrastructure in a metropolitan area due to a simulated earthquake event.
• Loss estimation of a priority national corridor due to an earthquake scenario predicted by USGS or other reliable sources.
• Simulated earthquake damage status - road closures/ limit access to State DOTs and can be used to plan or practice emergency planning on post-extreme events.
• Cost benefit analysis for seismic retrofitting projects and prioritizing retrofitting needs.
REDARS and FAF
Methodologies and Applications
DIALOGUE BOX TO SELECT NORTHRIDGE EQ
DROP-DOWN MENU:
ACCESS OF GROUND MOTION DATA
DROP-DOWN MENU: ACCESS BRIDGE DAMAGE & SYSTEM STATE DISPLAYS
REAL-TIME ASSESSMENT OF ALTERNATIVE EMERGENCY RESPONSE STRATEGIES: (ADD DETOUR LINK ALONGSIDE DAMAGED BRIDGE)
AFTER NETWORK ANALYSIS:
TRAVEL TIME & ECONOMIC LOSS DISPLAY
Tonnage on Highways, Railroads, and Inland Waterways: 2007

I-5 LA Area

I-40 Memphis Area

Sources: Highways: U.S. Department of Transportation, Federal Highway Administration, Freight Analysis Framework, Version 3.1, 2010. Rail: Based on Surface Transportation Board, Annual Carload Waybill Sample and rail freight flow assignments done by Oak Ridge National Laboratory. Inland Waterways: U.S. Army Corps of Engineers (USACE), Annual Vessel Operating Activity and Lock Performance Monitoring System data, as processed for USACE by the Tennessee Valley Authority; and USACE, Institute for Water Resources, Waterborne Foreign Trade Data, Water flow assignments done by Oak Ridge National Laboratory.
Freight Disruptions
Mississippi River Flooding
Freight Disruptions
Mississippi River Flooding
I-5 LA Case Study in the REDARS - With two Earthquake Scenarios
Simulated Results from REDARS Program
Damage and Loss Summary w/ 7.3 Magnitude EQ Located at Eastern LA

Seismic Hazards
- Walkthru Earthquake (year-seq):
  - 1053-1 (magnitude 7.3)
- Max. Component GMs and PGDs:
  - SA 1.0: 1.08g
  - Liq. PGD: 0.00in
  - SFR PGD: 0.00in

Component Damage
- 1. None
- 2. Slight: 41, 288, 0, 0
- 3. Moderate: 28, 126, 0, 0
- 4. Extensive: 54, 0, 0, 0
- 5. Complete: 33, 0, 0, 0
- Total: 1731, 3428, 1319462

Travel Impacts
- (reduction relative to baseline)
  - Lane Miles
    - 7 days: 1% 1%
    - 60 days: 1% 0%
    - 150 days: 0% 0%

Travel-Related $ Losses
- (in million $)
  - Cost per Day: $0.088, $0.030, $0.008
  - Total: $5.768

Loss Summary
- Upgrade Cost: $0.0
- Repair Cost: $20.4
- Travel Time: $5.8
- Total Loss: $26.2
Calculated Ground Motions
Permanent Ground Displacements
Trip Reductions at Day 7 for Freights
Components Damage States
Travel Time Increases at Day 7 for Freights
Damage and Loss Summary with 6.8 Magnitude EQ Located at Central LA

**Seismic Hazards**
- Walkthru Earthquake (year-seq): 215-1 (magnitude 6.8)
- Max. Component GMs and PGDs:
  - SA 1.0: 0.90g
  - Liq. PGD: 0.00in
  - SFR PGD: 0.00in

**Component Damage**

<table>
<thead>
<tr>
<th>Damage Level</th>
<th>Bridge</th>
<th>ApFill</th>
<th>Tunl</th>
<th>Pvmnt</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>1486</td>
<td>2532</td>
<td>1319462</td>
<td></td>
</tr>
<tr>
<td>Slight</td>
<td>119</td>
<td>896</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Extensive</td>
<td>46</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Complete</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Travel Impacts**
- (reduction relative to baseline)
  - Lane Miles: 7 days: 2%, 60 days: 1%, 150 days: 0%
  - Trips: 4%, 1%, 0%

**Travel-Related $ Losses**
- $0.169
- $0.059
- $0.026
- Total: $11.92

**Loss Summary**
- Upgrade Cost: $0.0
- Repair Cost: $37.1
- Travel Time Cost: $11.9
- Total Loss: $49.0
Component Damage States
Calculated Ground Motions
Travel Time Increases at Day 7 for Freight
## Average National Daily FAF Truck VMT: 2007

<table>
<thead>
<tr>
<th></th>
<th>Before Damage</th>
<th>After Damage</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMT</td>
<td>5,835,180,871</td>
<td>5,852,841,251</td>
<td>17,660,379</td>
</tr>
</tbody>
</table>

## Average National Daily Ton-miles (VMT x 18 tons per truck): 2007

<table>
<thead>
<tr>
<th></th>
<th>Before Damage</th>
<th>After Damage</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton-miles</td>
<td>105,033,255,678</td>
<td>105,351,142,518</td>
<td>317,886,822</td>
</tr>
</tbody>
</table>

## Estimated National Cost Per Day (ton-miles x $0.1654 Revenue Per Ton-mile): 2007

<table>
<thead>
<tr>
<th></th>
<th>Before Damage</th>
<th>After Damage</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$17,372,500,489</td>
<td>$17,425,078,972</td>
<td>$52,578,480</td>
</tr>
</tbody>
</table>
Turner–Fairbank Highway Research Center
Research and Development Programs
http://www.fhwa.dot.gov/research/tfhrc/programs/

Exploratory Advanced Research
Infrastructure
Operations
Safety
Safety Research and Development (R&D) Program

Research Focus Areas – The research focus areas of the Safety R&D program reflect current FHWA strategic focuses.

Comprehensive Approach to Safety – Data definition, data collection, analytical tools supporting data-driven safety decisions, and evaluation of safety treatments.

Human Factors – Examining drivers’ capabilities and limitations when interacting with the vehicle and the roadway to inform better roadway design. Other research topics include distraction, older drivers, traffic management centers, and the effects of changes in visibility.

Intersection Safety – Increasing our understanding of intersection safety, and establishing short- and long-term strategies for safety improvements. The design and evaluation of non-traditional intersections and interchanges, and development of systems to improve safety in or near intersections.

Pedestrians and Bicyclists Safety – Fostering professional awareness of pedestrian and bicyclist safety issues, developing and evaluating countermeasures, and providing engineering resources for practitioners at national, State, and local levels.

Roadway Departure – Research emphasizing keeping vehicles on the roadway, and minimizing the consequences of leaving the roadway. Advancing tools and technologies for crashes involving roadway departures and collisions with roadside hardware.

Speed Management – Research to develop and test engineering approaches to speed management, and to encourage wider adoption of appropriate travel speeds.

Visibility – Research to improve visibility on and along the roadway, and of traffic control devices.
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Thank you for your attention.

Questions?