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 Office
- 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

Exploratory Advanced Research (EAR) Program

http://www.fhwa.dot.gov/advancedresearch/index.cfm

U.S. Department of Transportation
Federal Highway Administration

Search | Feedback

EXPLORATORY ADVANCED RESEARCH

FHWA > Exploratory Advanced Research

- HOME
- ABOUT
  - *General*
  - *Focus Areas*
  - *History*
- RESEARCH
- PUBLICATIONS
  - *Articles*
- EVENTS
  - *Upcoming*
  - *Past*
- CONTACTS
- LINKS OF INTEREST

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

Exploratory Advanced Research (EAR) Program

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

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

Dr. David Kuehn
(202) 493-3414
david.kuehn@dot.gov

Terry Halkyard
(202) 493-3467
Terry.halkyard@dot.gov

Federal Business Opportunities

FedBizOpps.GOV

★ FEDBIZOPPS.GOV Federal Business Opportunities

IAE E-GOV USA.gov

Federal Business Opportunities

Home | Getting Started | General Info | Opportunities | Agencies | Privacy

Search more than **29,100*** active federal opportunities.

Posted Date: Last 90 Days Set-Aside Code: Any

Place of Performance: Any State or Territory Type: Any

Keyword / Solicitation #: Agency:

Search

Additional criteria and multiple selections are available on the advanced search form.

* Notices posted within the last 90 days.

ATTENTION: Agency users are responsible for properly uploading controlled, unclassified materials to FBO using the access control procedures for document packages and attachments detailed in the FBO Buyers Guide. Do not upload ANY classified materials to FBO.

Buyers / Engineers

Government users may post, manage, and award opportunities.

Username

Password

Login

- View Opportunities
  No login is required to view opportunities.
- Register Now
- Password Reminder
- Recovery FAQs

Vendors / Citizens

Vendors and citizens may search, monitor, and retrieve opportunities.

Username

Password

Login

- Find Opportunities
  No login is required to view opportunities.
- Register Now
- Password Reminder
- Recovery FAQs

RECOVERY

Locate actions funded by the American Recovery and Reinvestment Act.

SEARCH RECOVERY OPPORTUNITIES

SEARCH RECOVERY AWARDS

FBO RECOVERY REPORTS

- Click here for Opportunities
- Click here for Awards

Click here to learn more.

SMALL BUSINESS EVENTS

Learn more about the Small Business Central Event Listing or search now for events.

SEARCH SMALL BUSINESS EVENTS

VENDOR COLLABORATION

FBO now contains the Vendor Collaboration Central Event Listing. Learn more or search.

VENDOR COLLABORATION

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

The Solution?

HMA from Plant

Encapsulated RFID Tag

Haul Truck

Paver

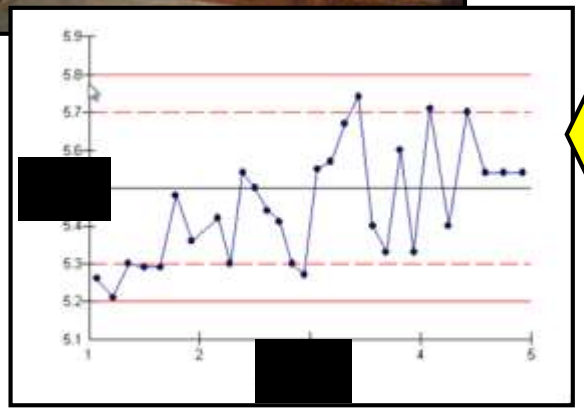
Compaction

Finished Pavement

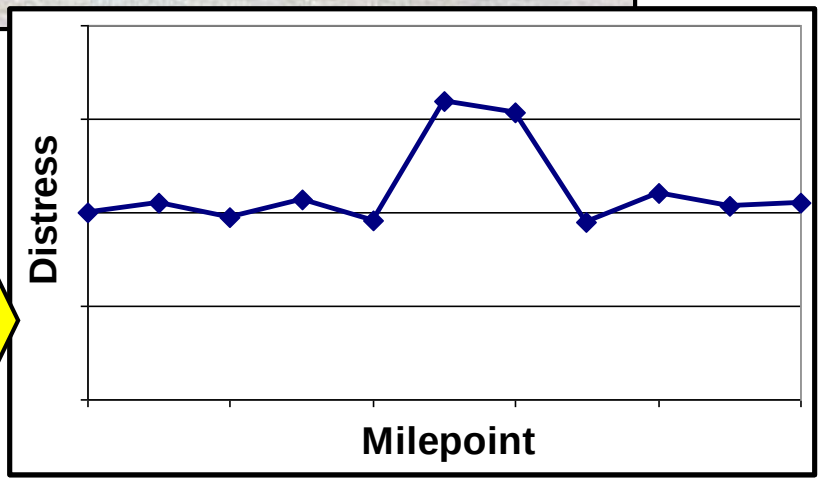
Tags scanned when convenient after construction

Vehicle with RFID Reader and GPS

Tracking: The Problem



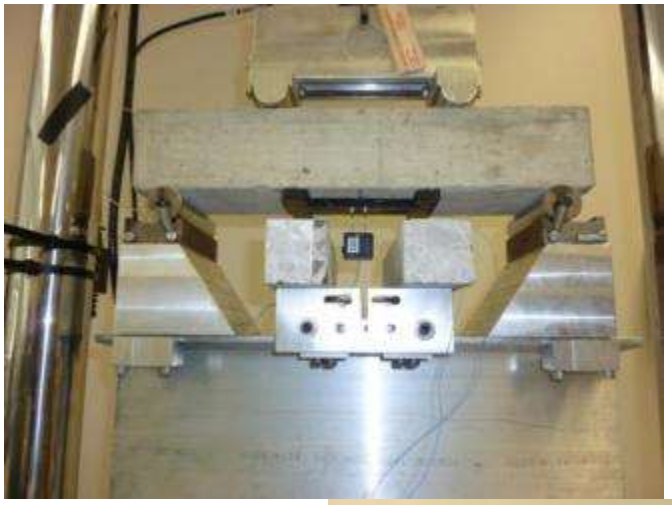
Link??

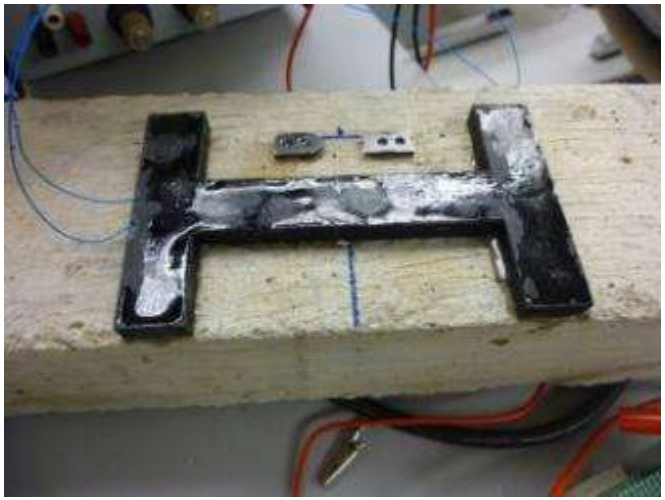


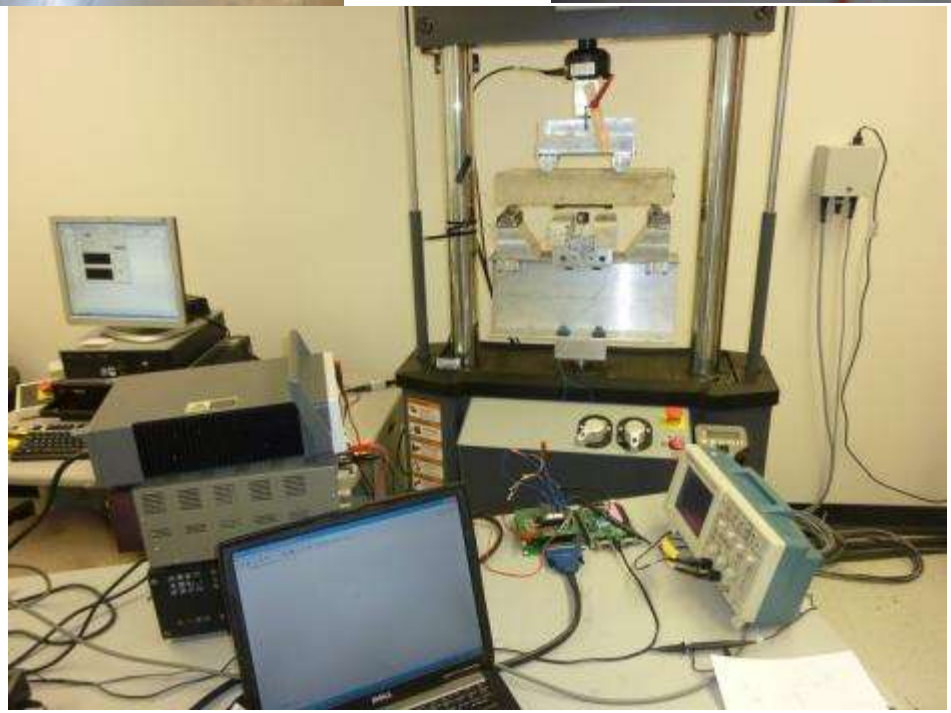
Pavement Construction

Pavement Management

Data Interpretation: Damage Estimation





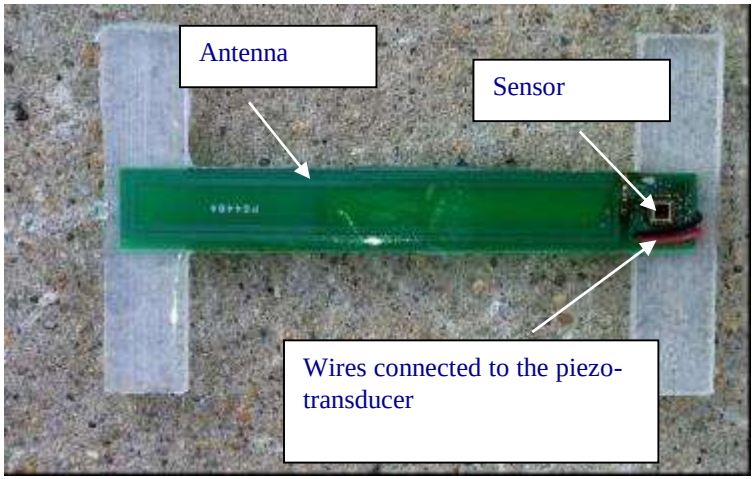


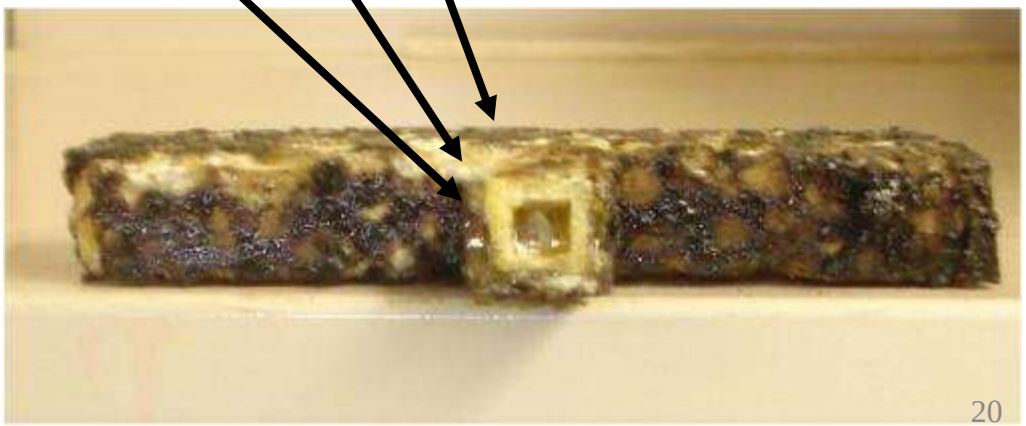
Power Dissipation Scale

$10^{9}W$	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
$10^{-6}W$	
$10^{-9}W$	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

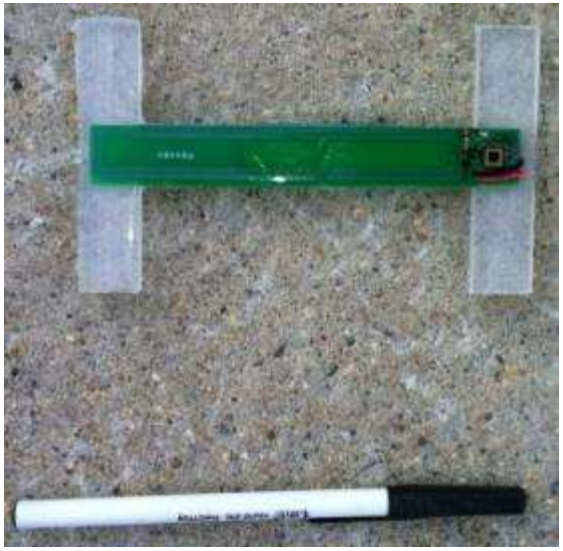
Design of robust packaging system

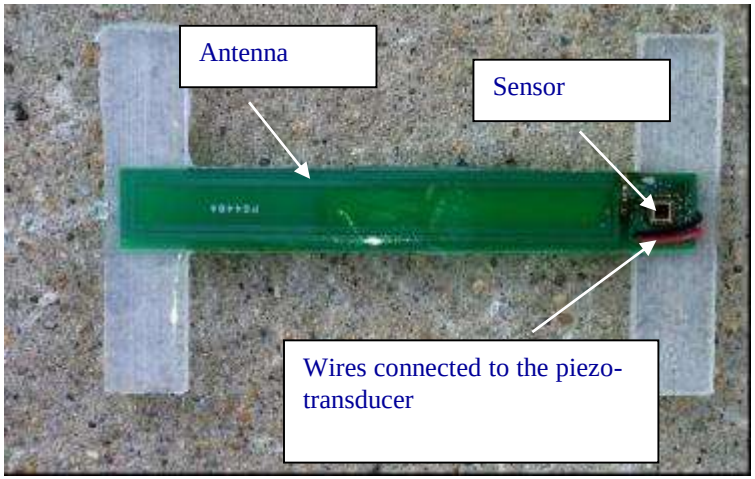
1- Chemical + Mechanical protection : Epoxy layer
2- Thermal insulation: Polyurethane foam
3- Chemical + Mechanical protection: Epoxy layer

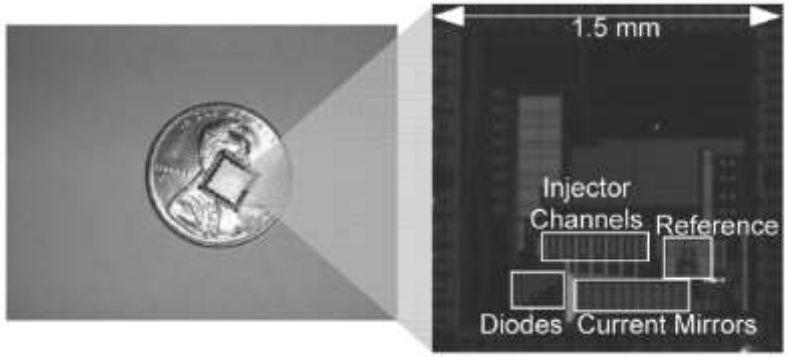




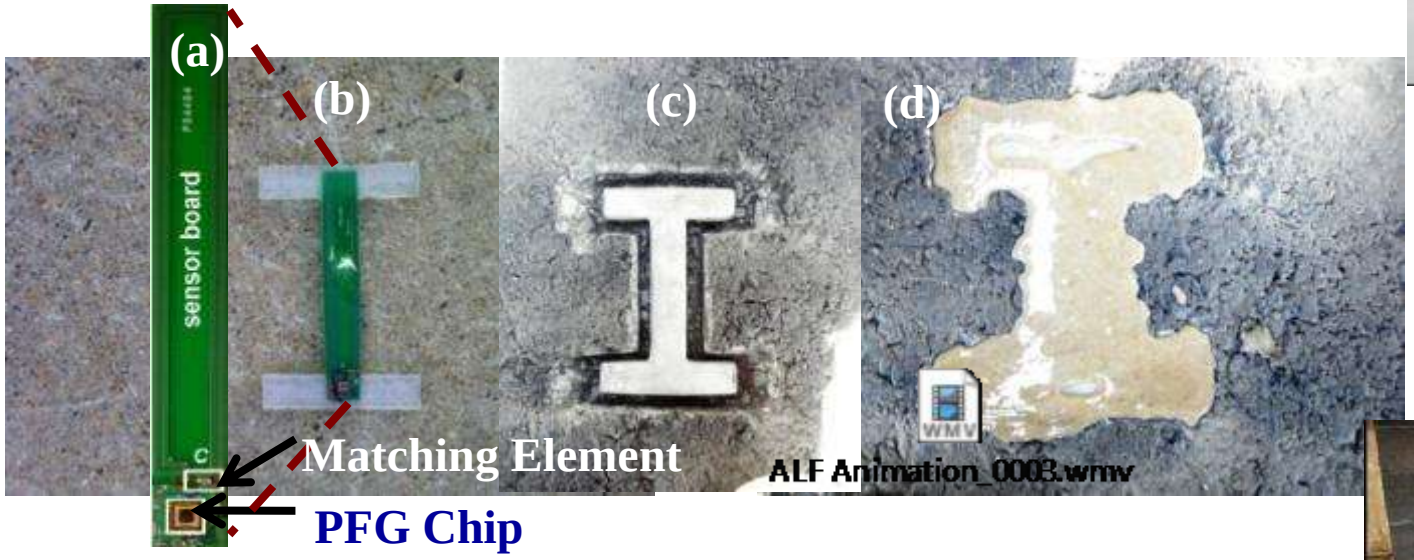
Packaging and Installation

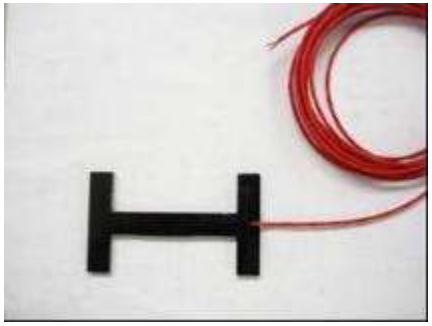






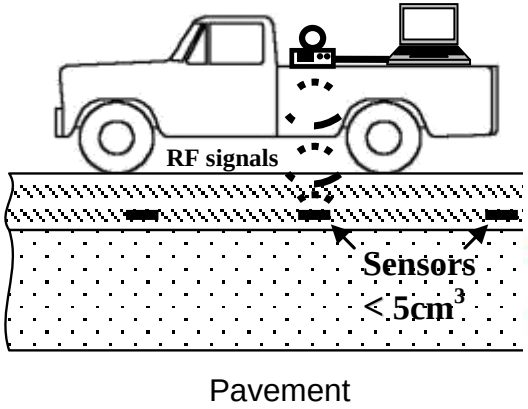
FHWA Field Study At the ALF

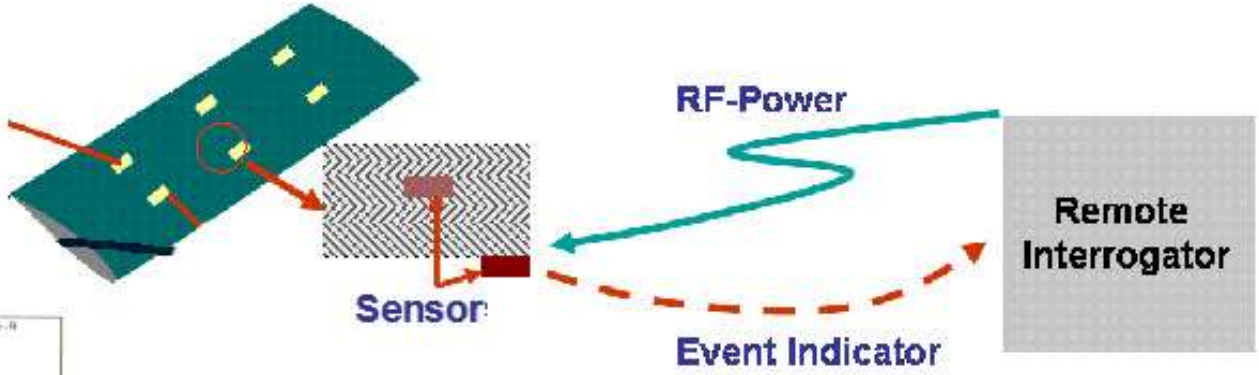


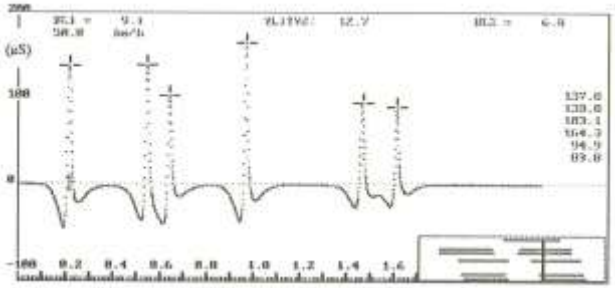


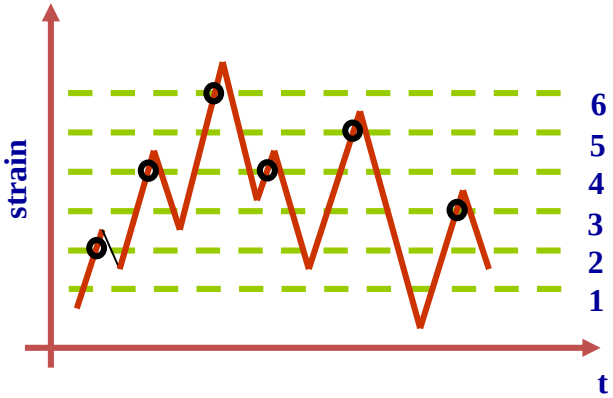
- 24 hours continuous testing: Sensor electronics and packaging survived the load.
- RFID and data collection interface needs to be more robust.

Envisioned monitoring system



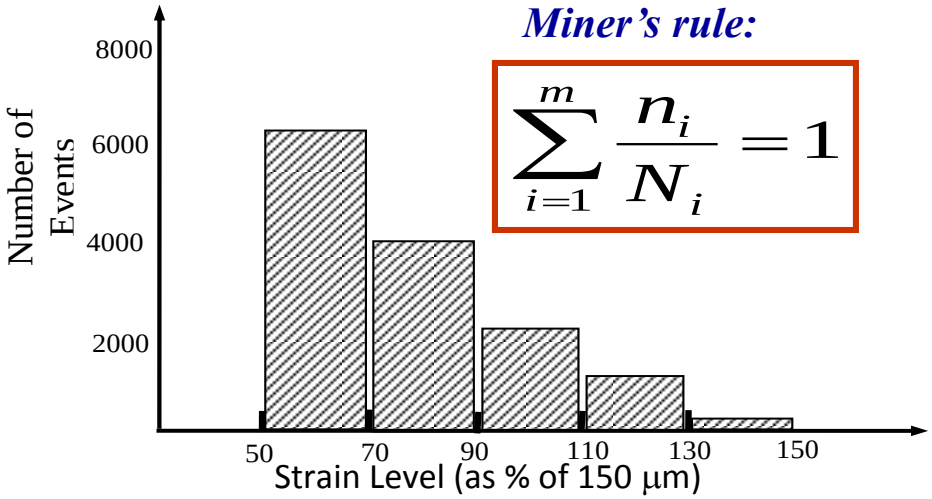






Miner's rule:

$$\sum_{i=1}^{m} \frac{n_i}{N_i} = 1$$



C.J. Miller Paving

Office of Infrastructure R & D Infrastructure

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

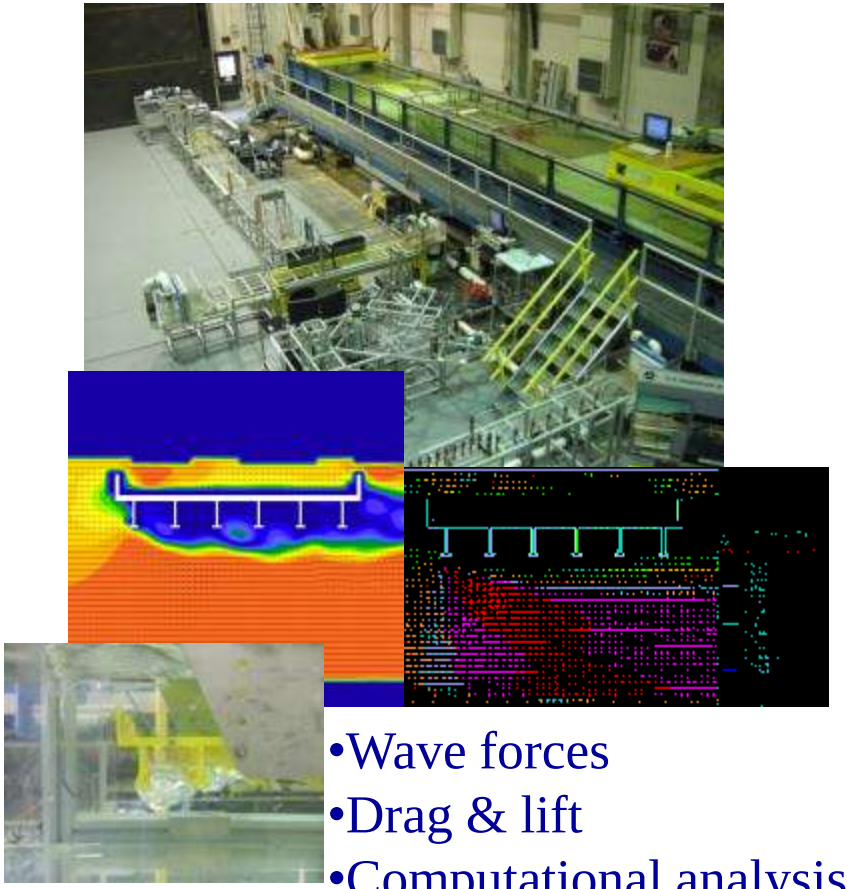
Hazard Mitigation Team

- 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

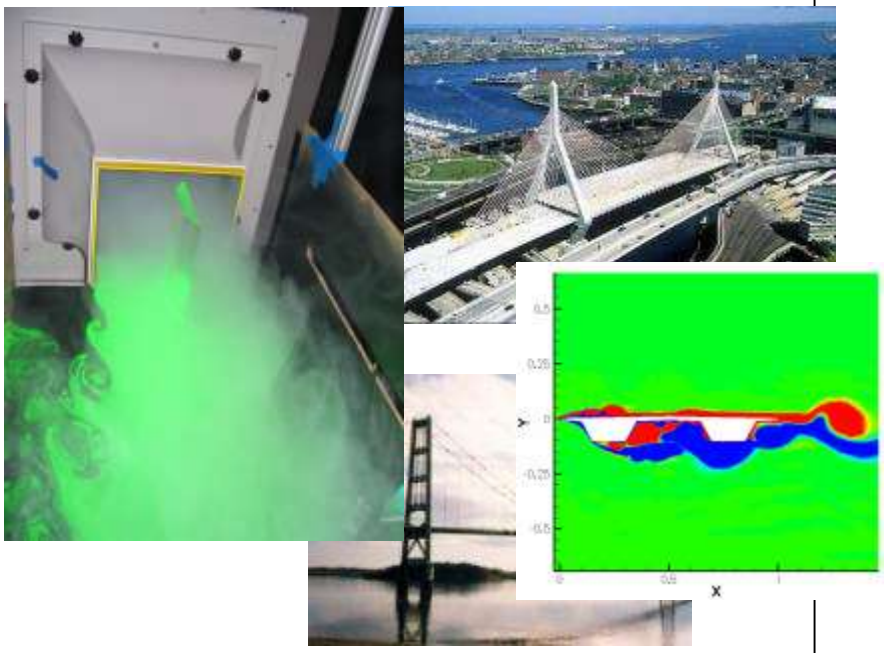
Hazard Mitigation Team

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

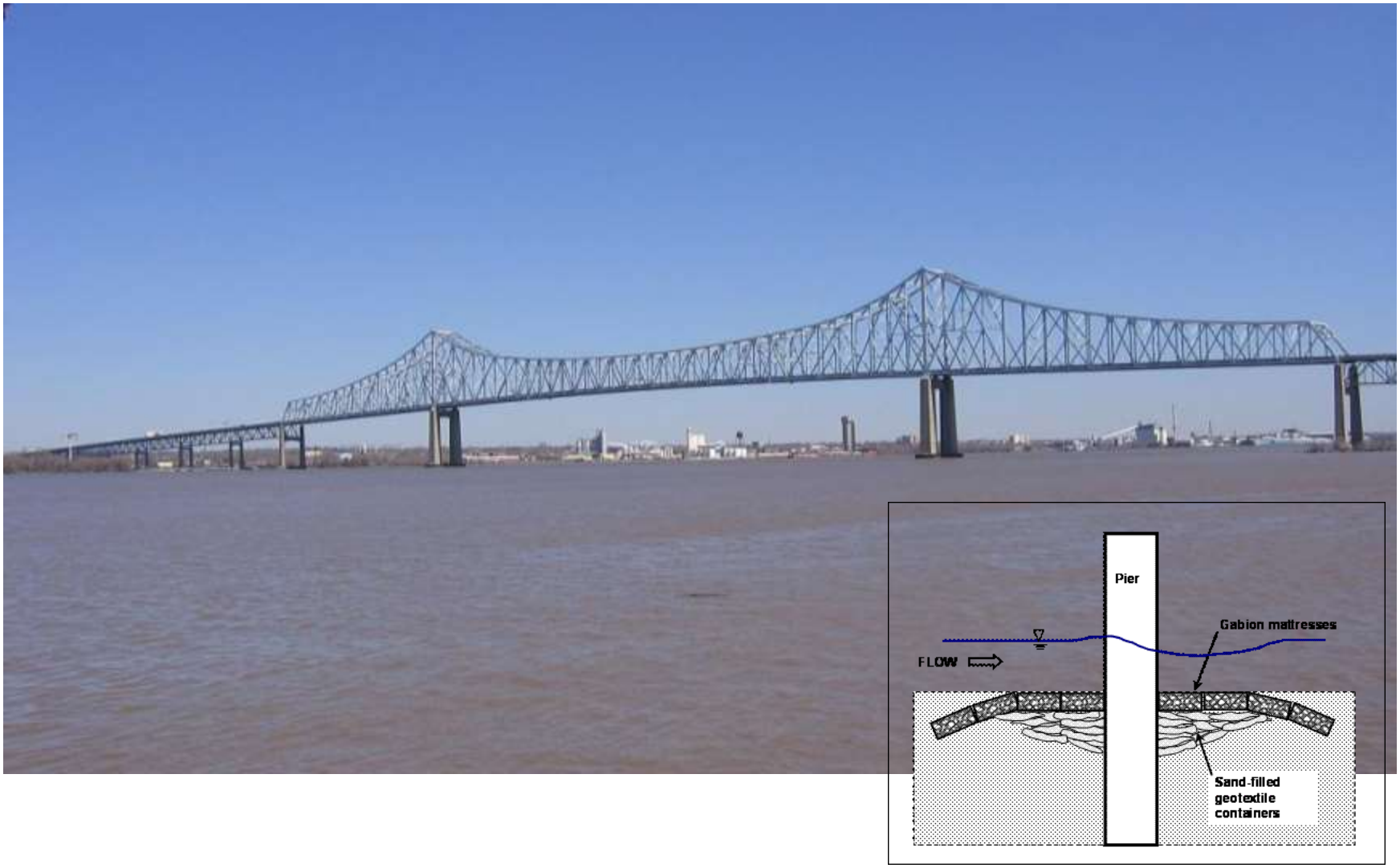
Hazard Mitigation Team

Wave Forces on Bridge Decks – Hurricane Katrina 2005 (cont'd)

Hazard Mitigation Team

Hazard Mitigation Team

Commodore Barry Bridge – USA, 2000



Office of Infrastructure R & D Infrastructure

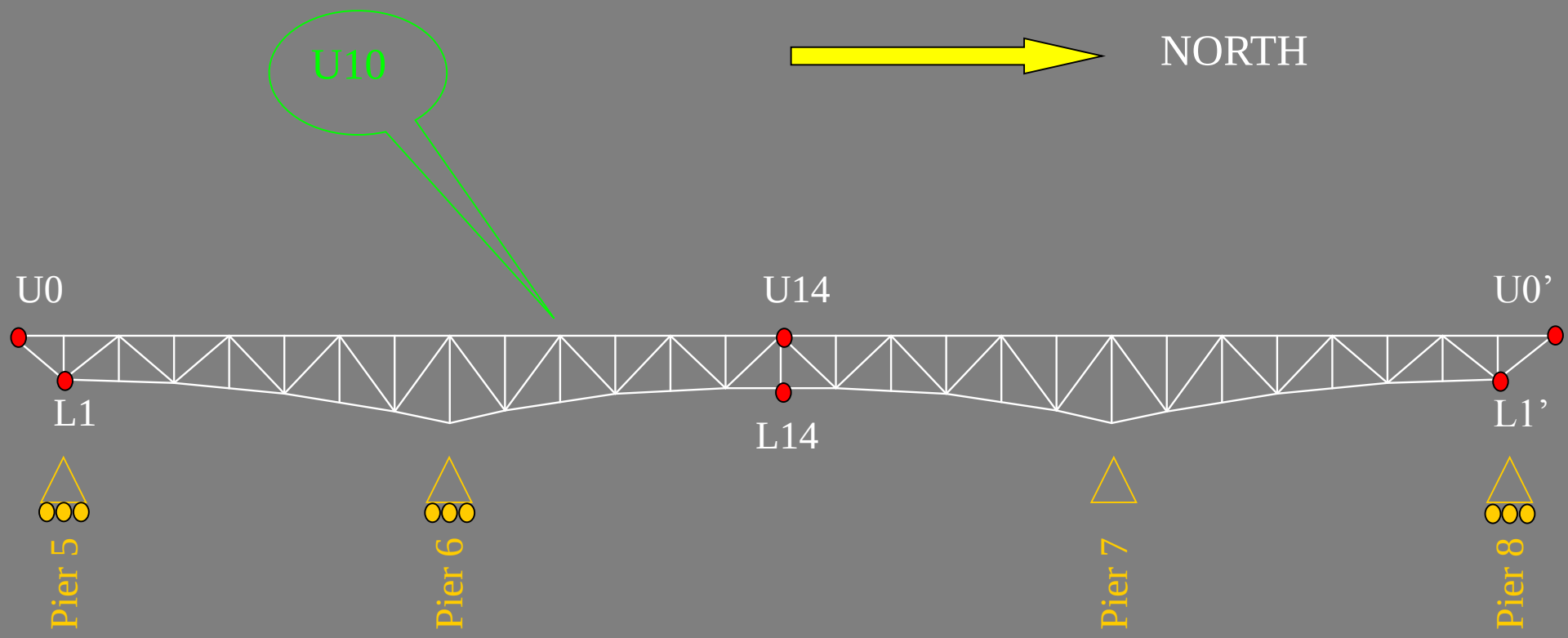
- Pavement Design and Construction
- Hazard Mitigation
- **Bridge and Foundation Engineering**

Bridge and Foundation Engineering Team

EXIT 118C
BUS EAST
11
460
460
Shawsville
Elliston
1/4 MILE
EXIT ONLY

Simms St
EXIT 1 MILE

Bridge and Foundation Engineering Team



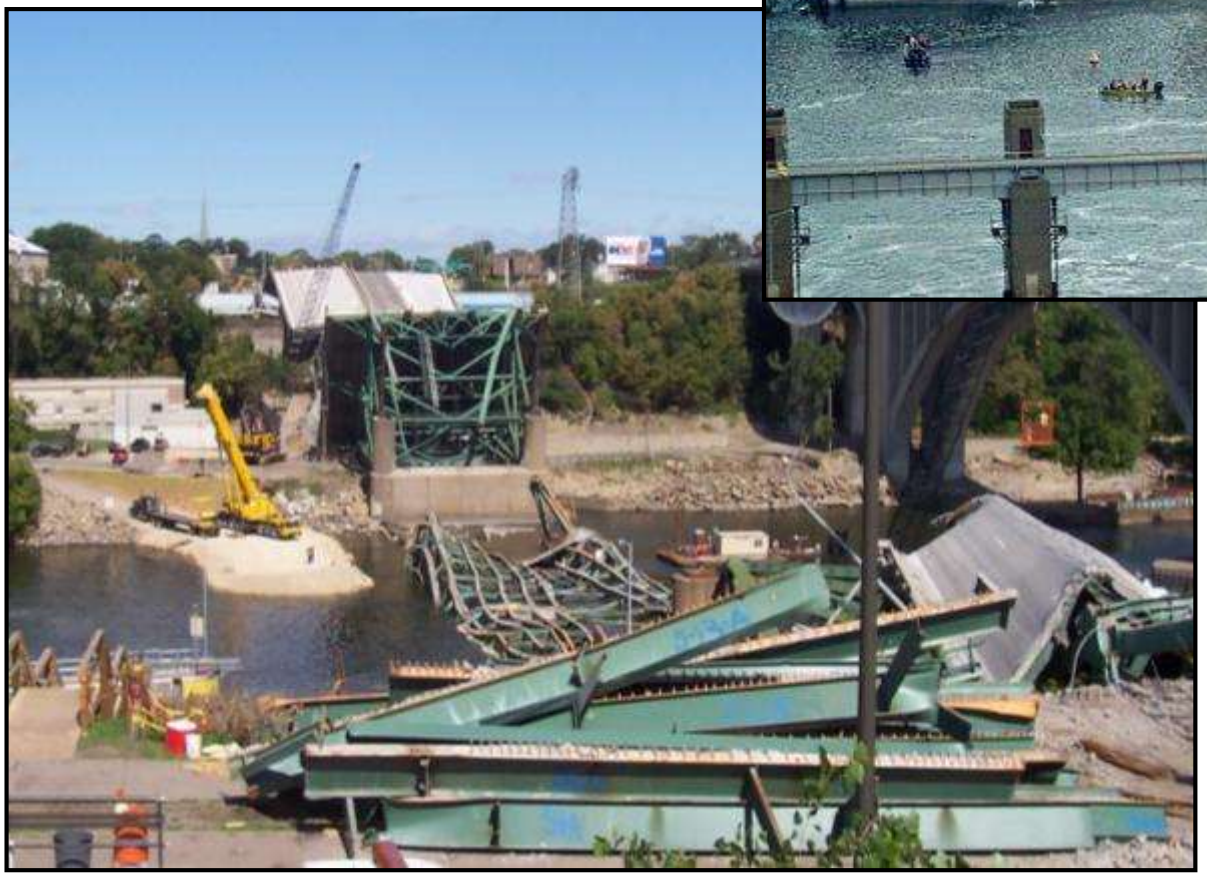
Analysis of the Structure

Bridge and Foundation Engineering Team

I-35W Bridge Collapse Investigation

Bridge and Foundation Engineering Team

Recovery



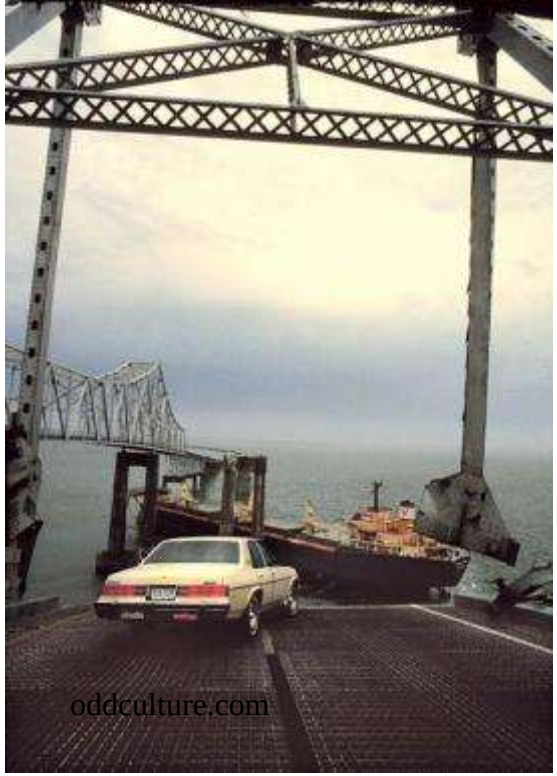
Bridge and Foundation Engineering Team

Bridge and Foundation Engineering Team

NCHRP 12-84 Load Frame

alviassociates.com

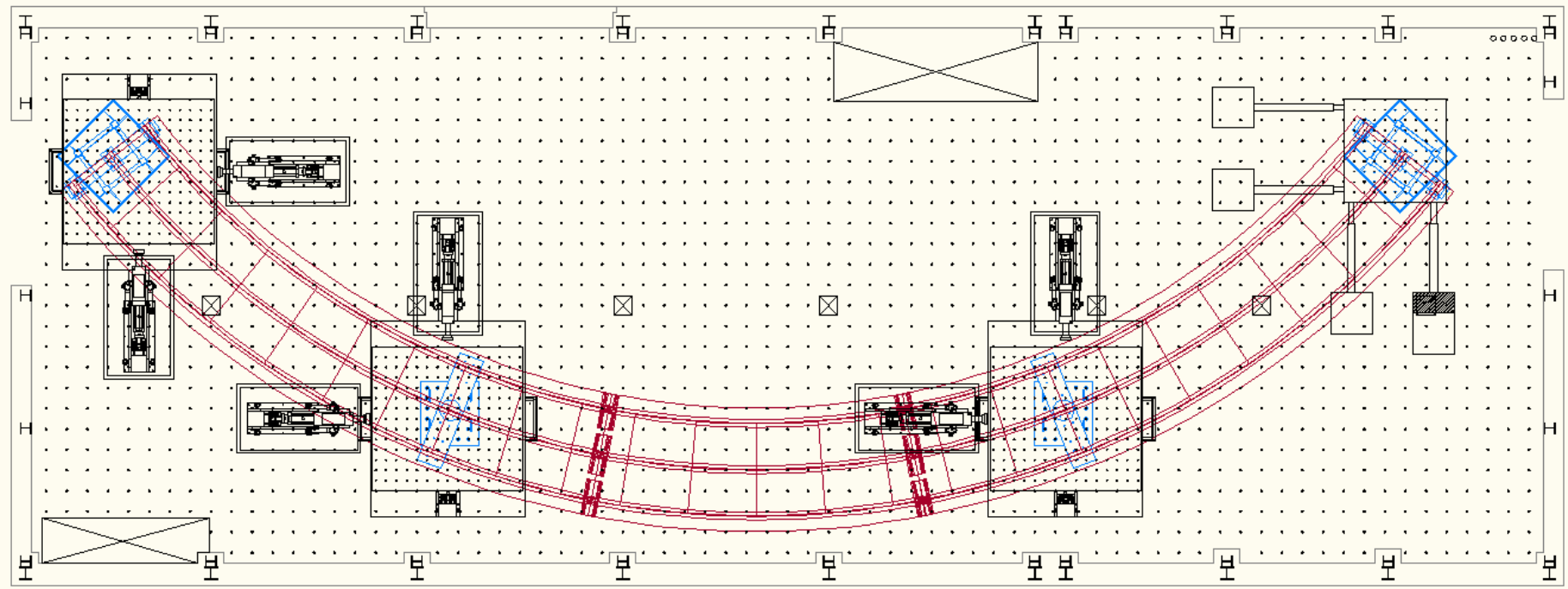
questontheloop.blogspot.com



U.S. Coast Guard

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 Wibowo, Chunli Wei, Ahmad Saad, Nathan Harrison, Moustafa Al-Ani, and Dr. Arash Zhagi

Project Management: Kelly Lyttle

Seismic Behavior of Curved Highway Bridge

-
-

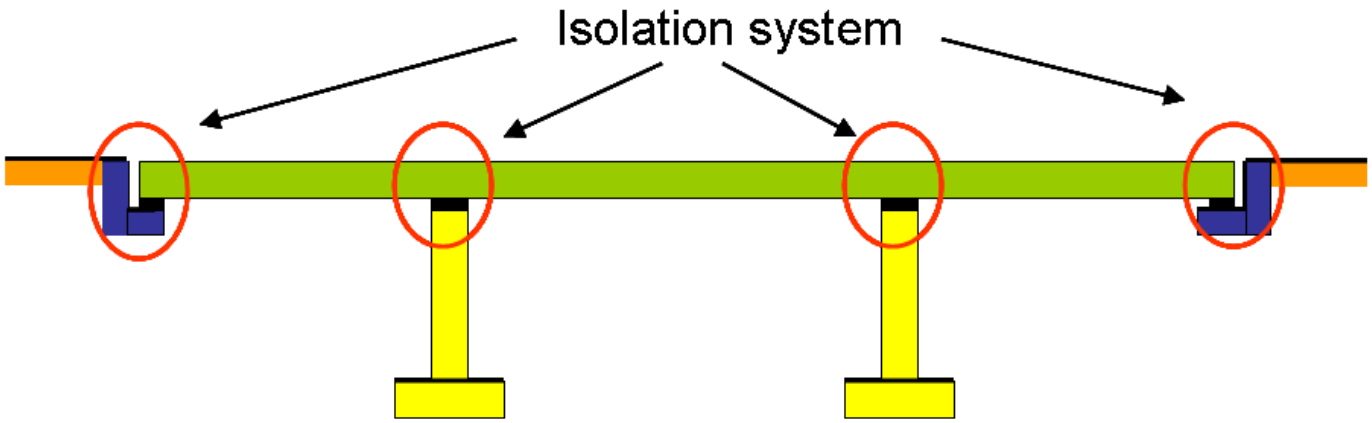
01/05/2012

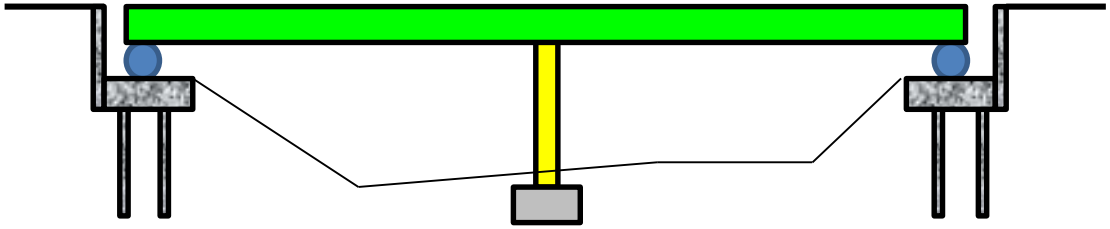
Seismic Behavior of Curved Highway Bridge

- 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

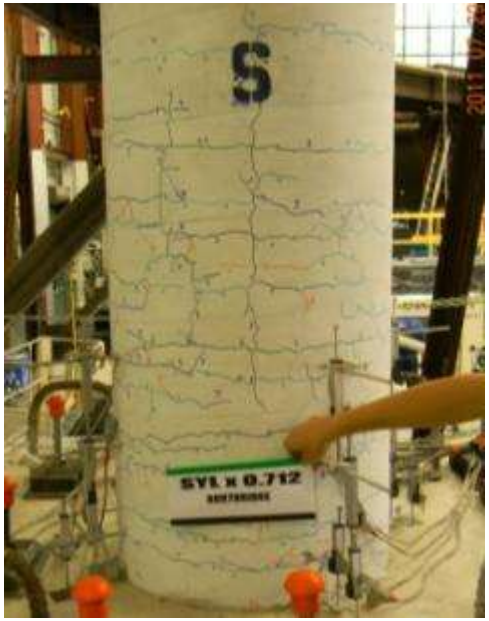




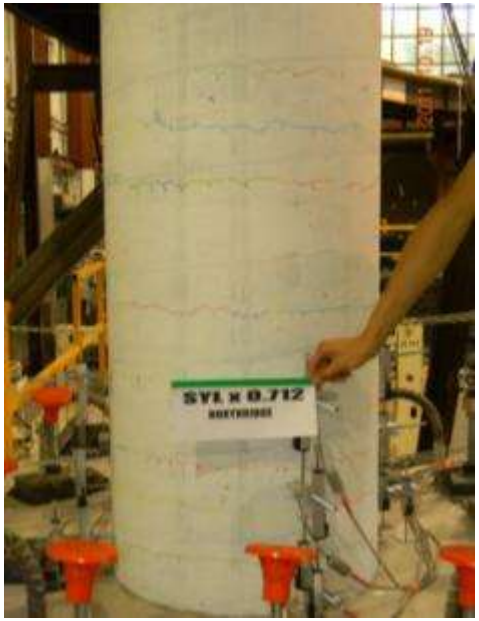
Bridge with Monolithic Pier-to-Deck Connection

Column Damage at 150% DE

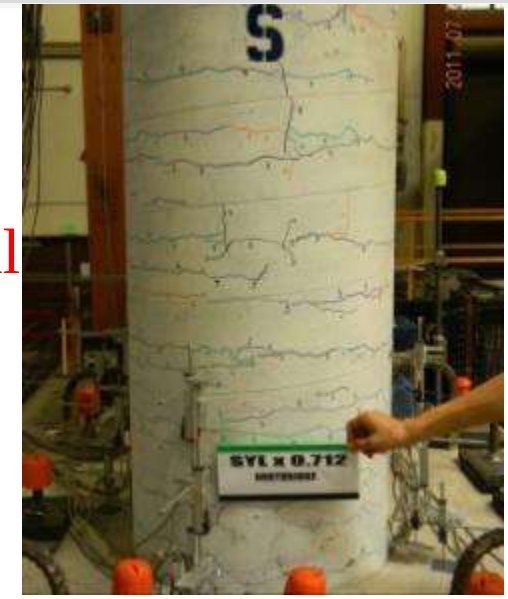
Pier 2
Conventional
Case



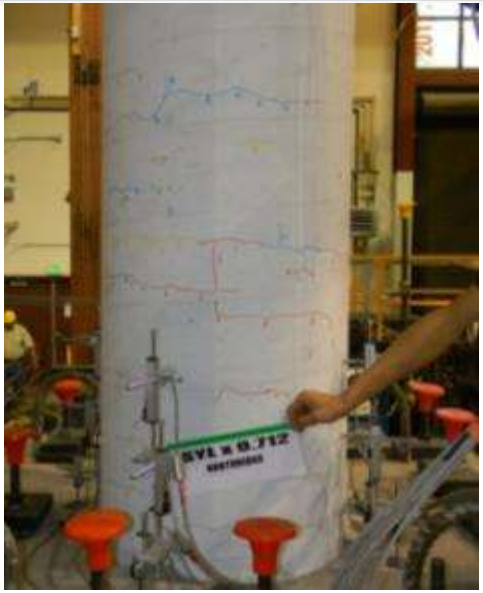
Pier 2
Full
Isolation
Case



Pier 3
Conventional
Case



Pier 3
Full
Isolation
Case

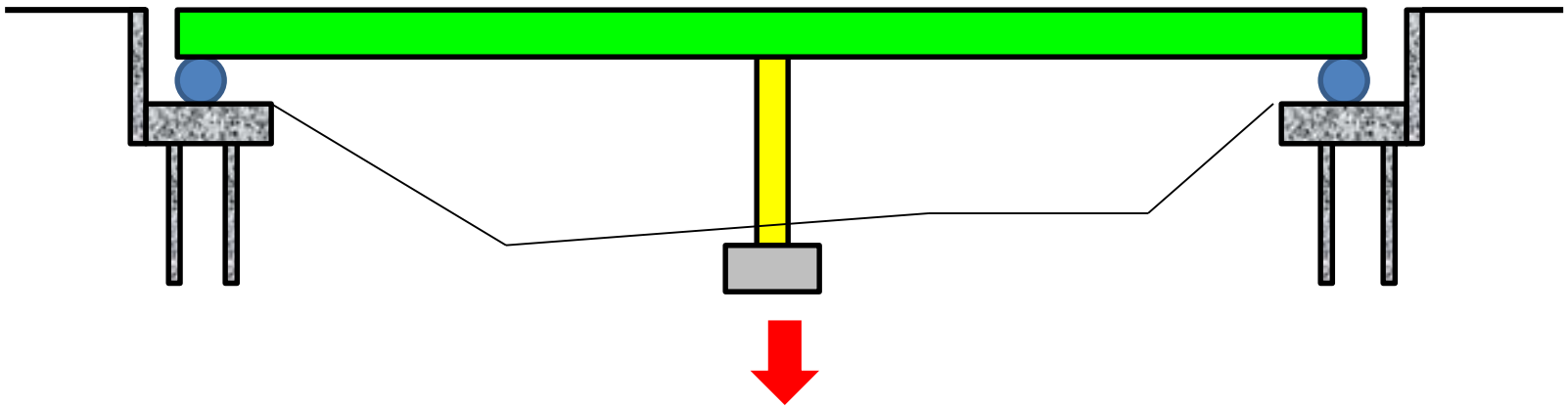


Curved Bridge: Full Isolation Case

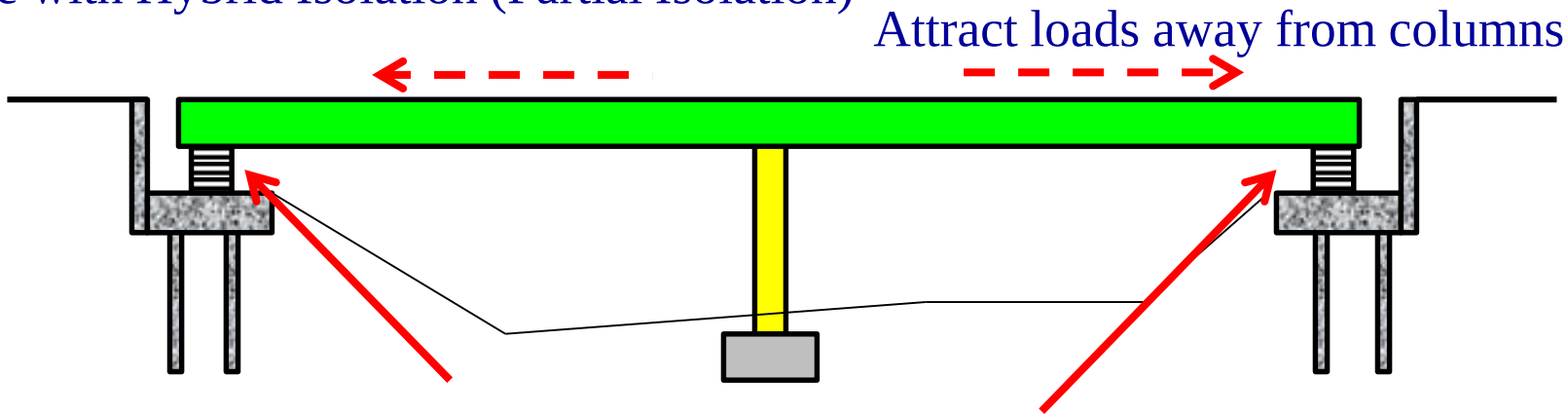
- Lengthen the period
- Reduction in column forces
- Increased displacement

Hybrid Isolation (Partial Isolation)

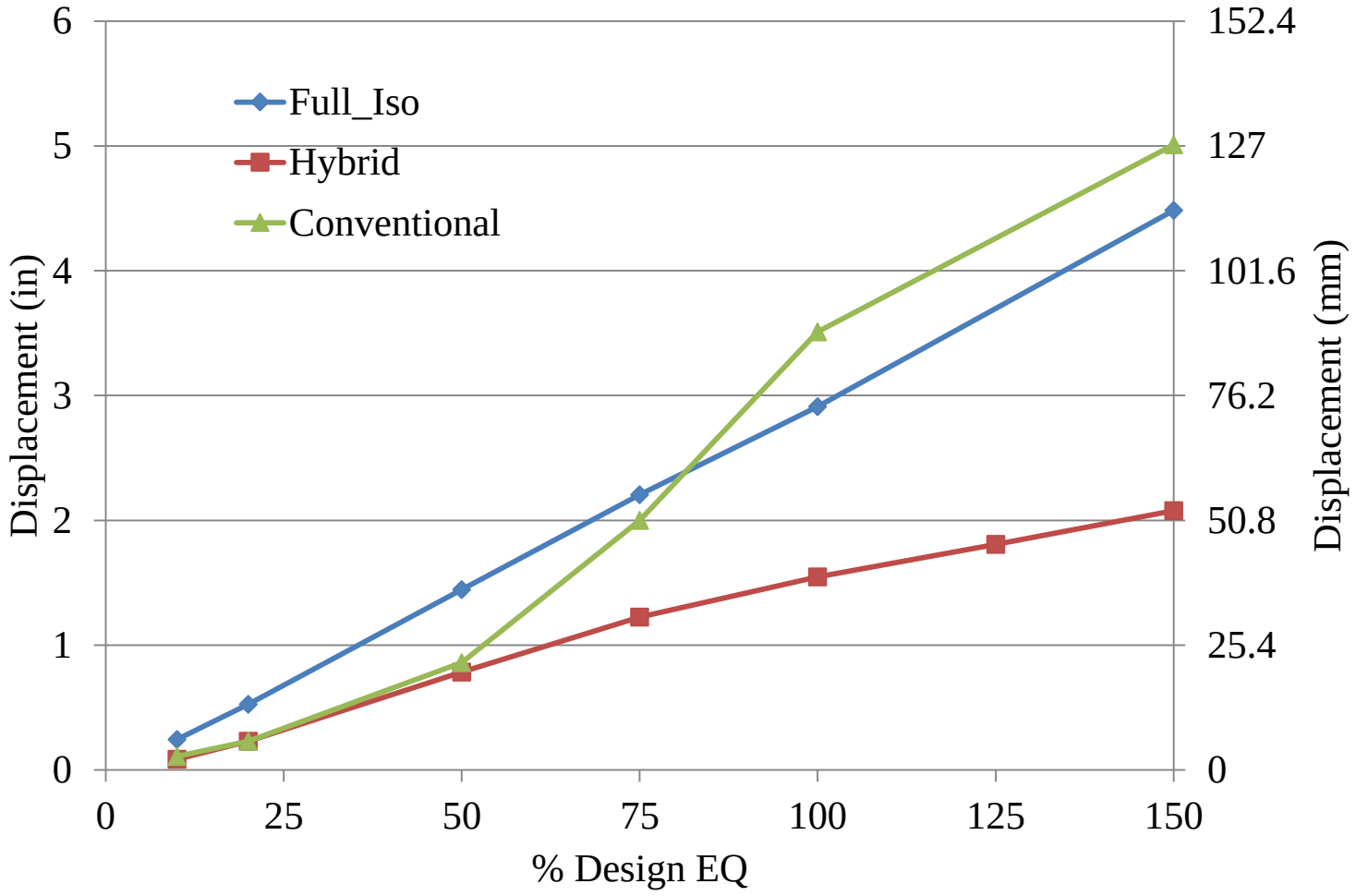
Bridge with Monolithic Pier-to-Deck Connection



Bridge with Hybrid Isolation (Partial Isolation)

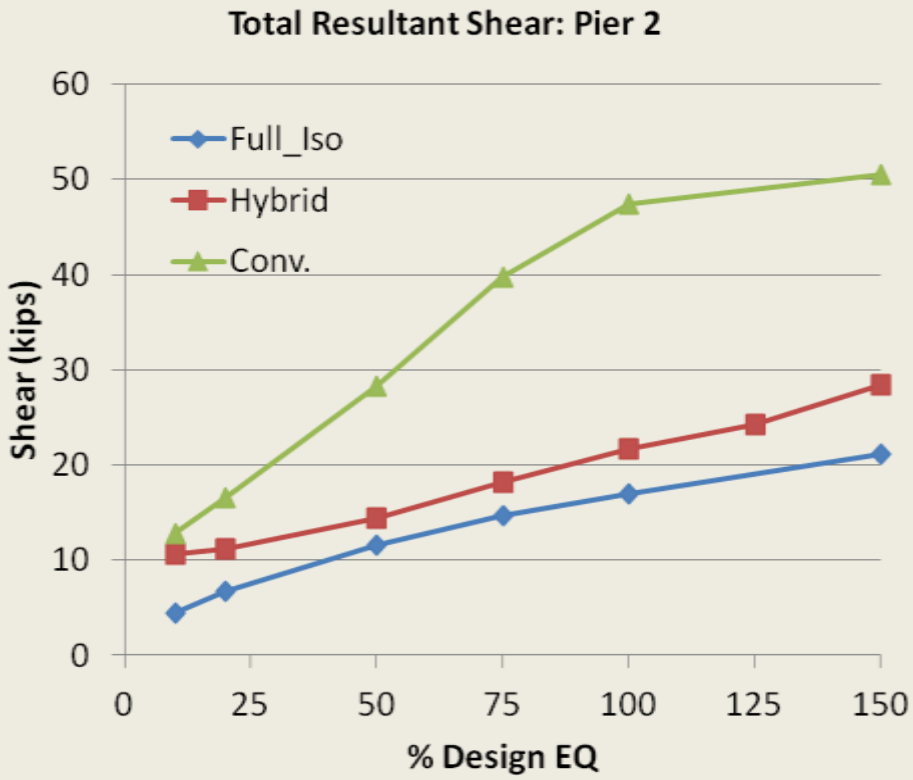


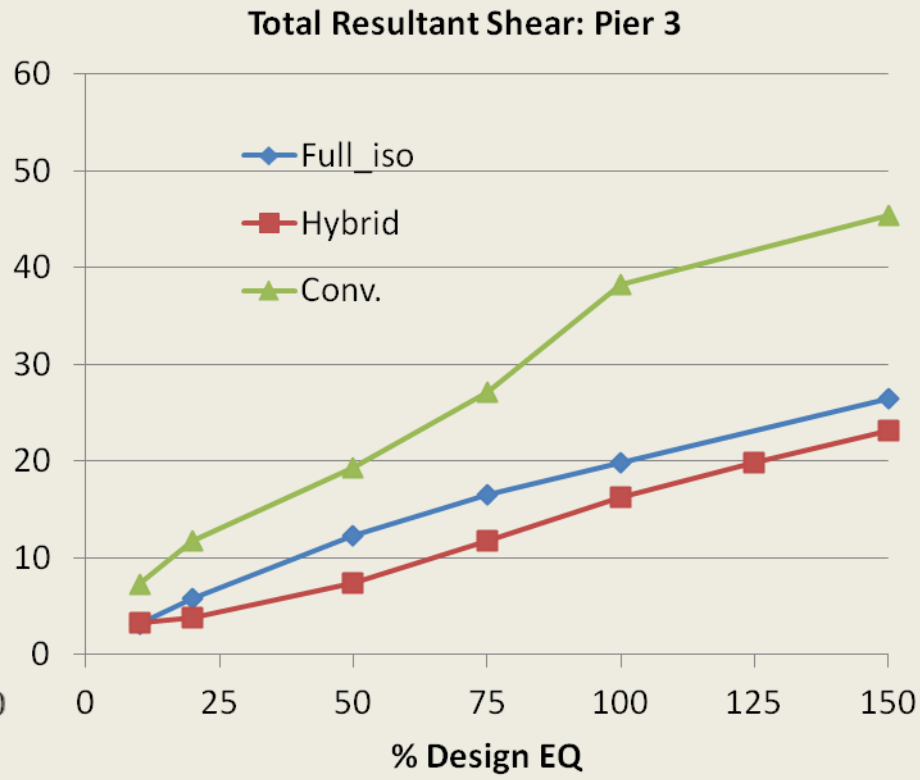
Superstructure Displacement



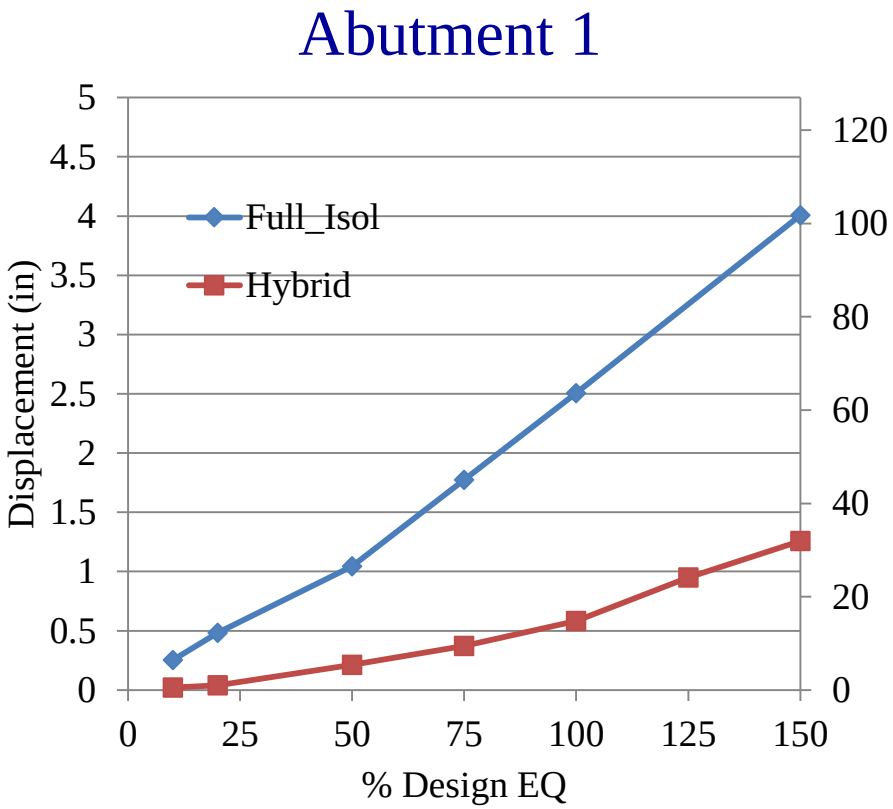
Note: These are resultant superstructure displacement at the center of the bridge (i.e. mid-span of Span 2).

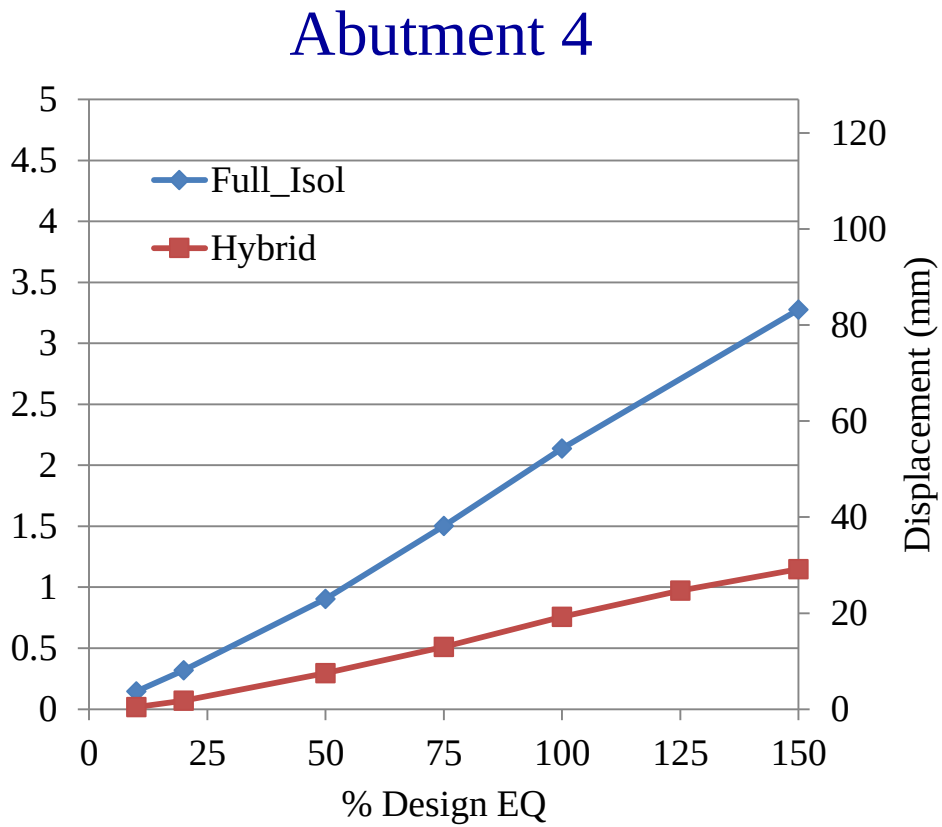
Support Shear Forces





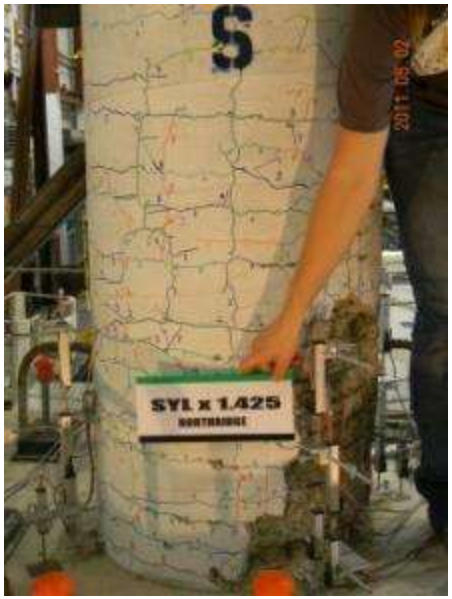
Isolator Displacements



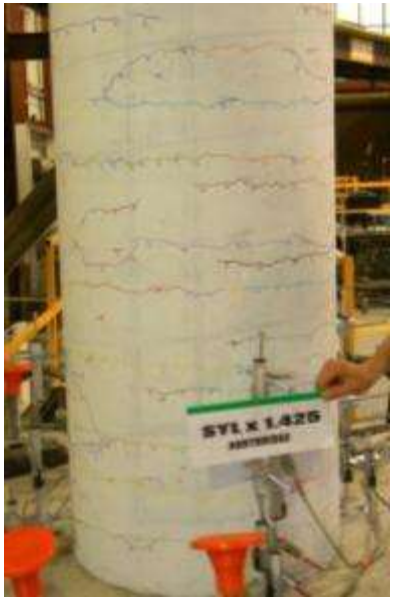


Column Damage at 300% DE

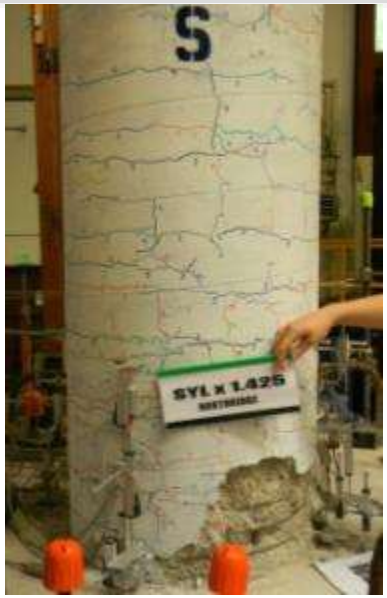
Pier 2
Conventional
Case



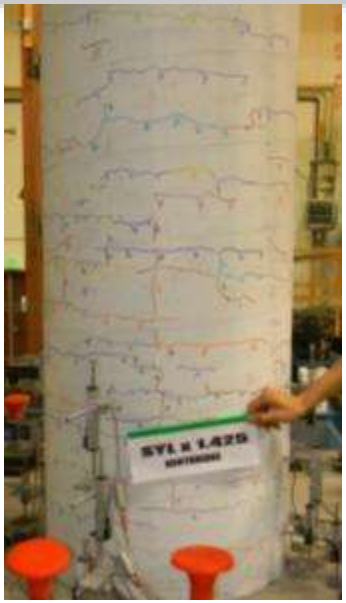
Pier 2
Full
Isolation
Case



Pier 3
Conventional
Case



Pier 3
Full
Isolation
Case



Hazard Mitigation Team

Abutment Uplift: Conventional Case at 350% DE

01/24/2012

01/31/2012

21/02/2012 19:12

01/05/2012

21/02/2012 15:38

21/02/2012 15:38

21/02/2012 15:40

21/02/2012 19:10

21/02/2012

21/02/2012 15:41

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):

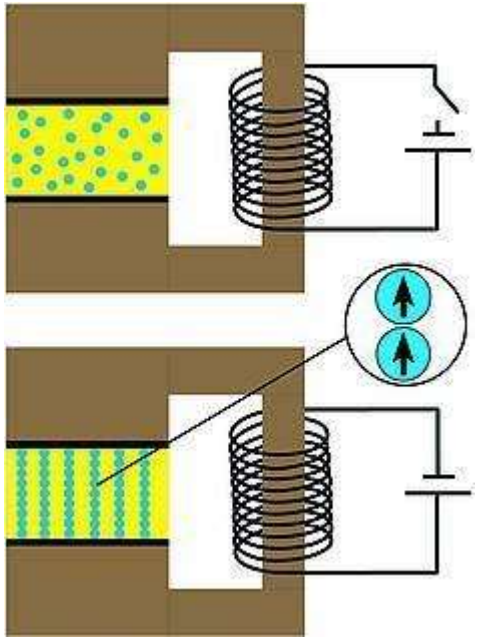
Magneto-rheological fluids MRF):

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



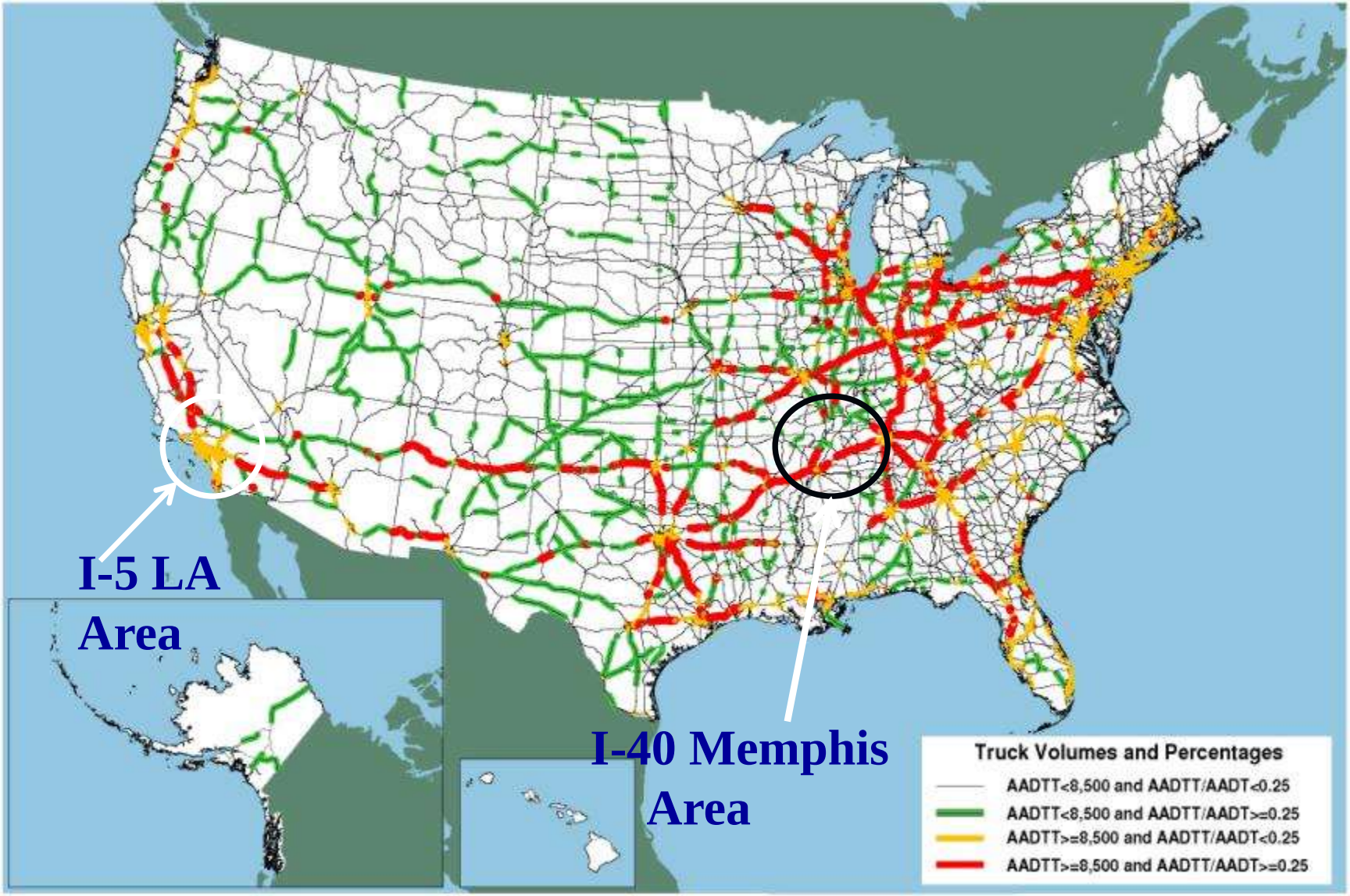
http://www.cesma.de

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

Major Truck Routes on the National Highway System: 2007



Note: AADTT is average annual daily truck traffic and includes all freight-hauling and other trucks with six or more tires. AADT is average annual daily traffic and includes all motor vehicles.
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.1, 2010.

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

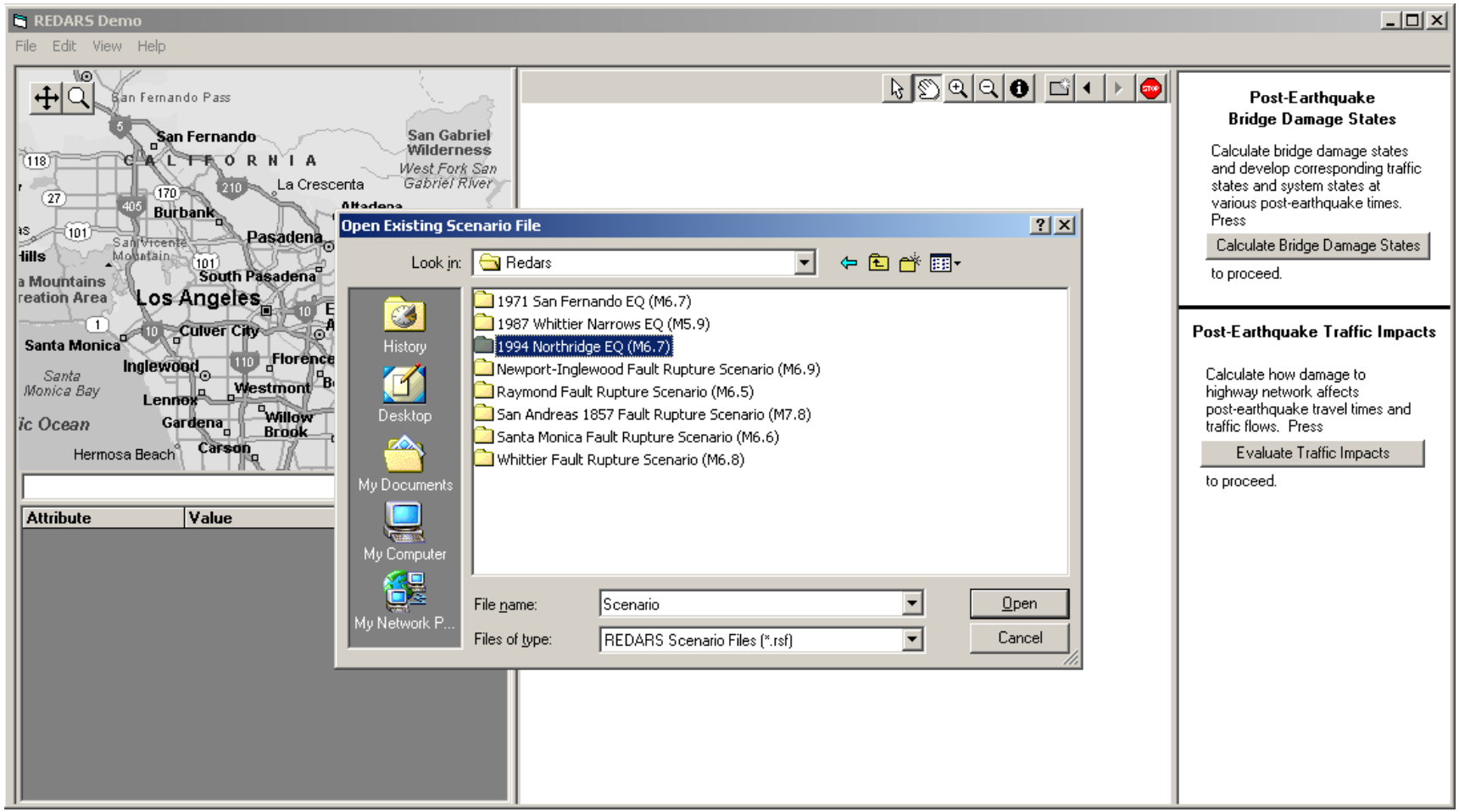
- Using REDARS Program to perform earthquake damage/ loss estimations in one of most possible scenarios
  - Direct Loss of Bridge/ Highway Structures, including repairing cost
  - Travel Congestions/ Time Increases.
  - Recovering Time/ Resilience
- Using FAF to perform Data Analysis due to Bridge/Highway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

Anticipated Results

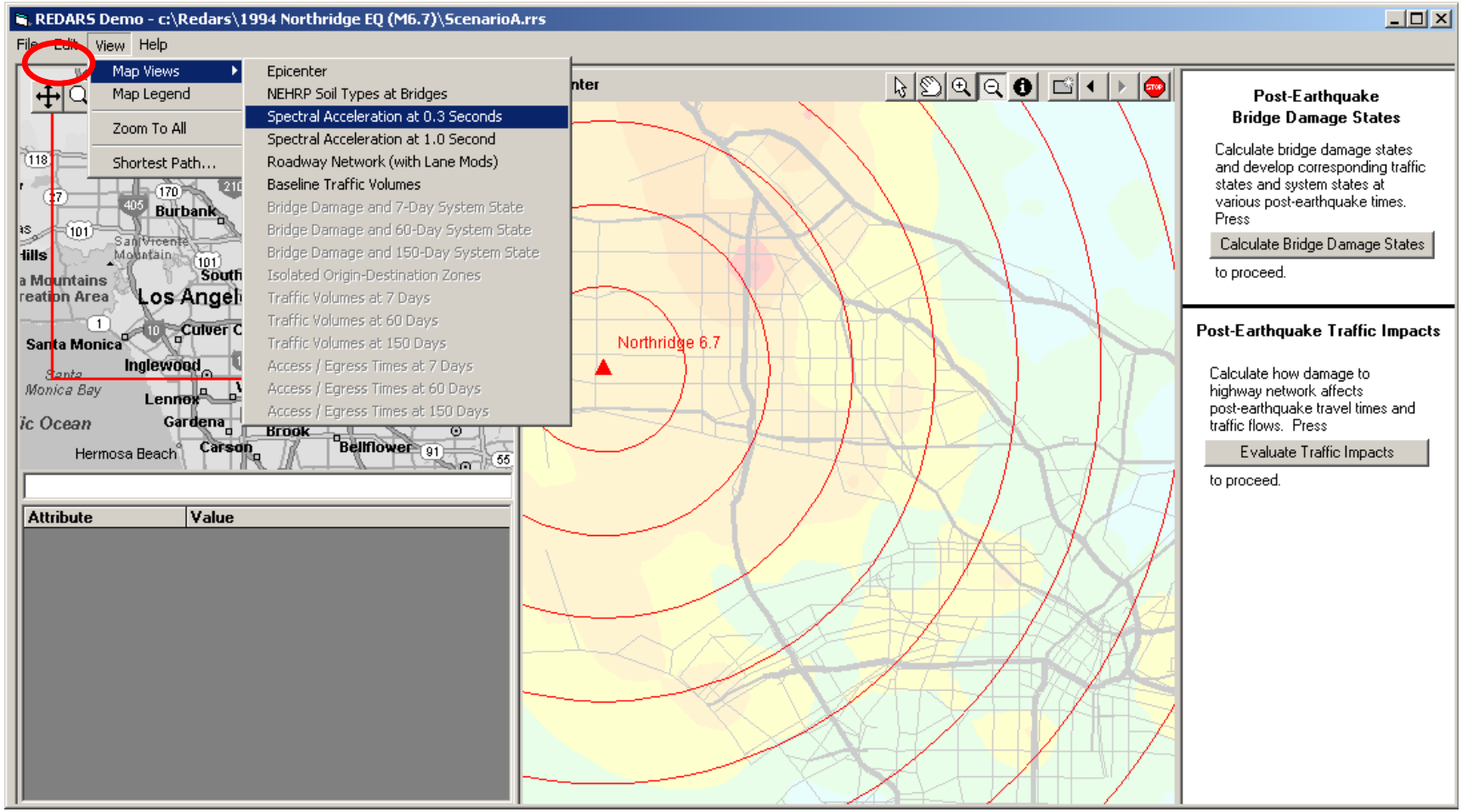
- Cost estimate of transportation infrastructure in a metropolitan area due to a simulated earthquake event.
- Loss estimation of a priority national corridor due to an earthquake scenario predicted by USGS or other reliable sources.
- Simulated earthquake damage status - road closures/ limit access 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

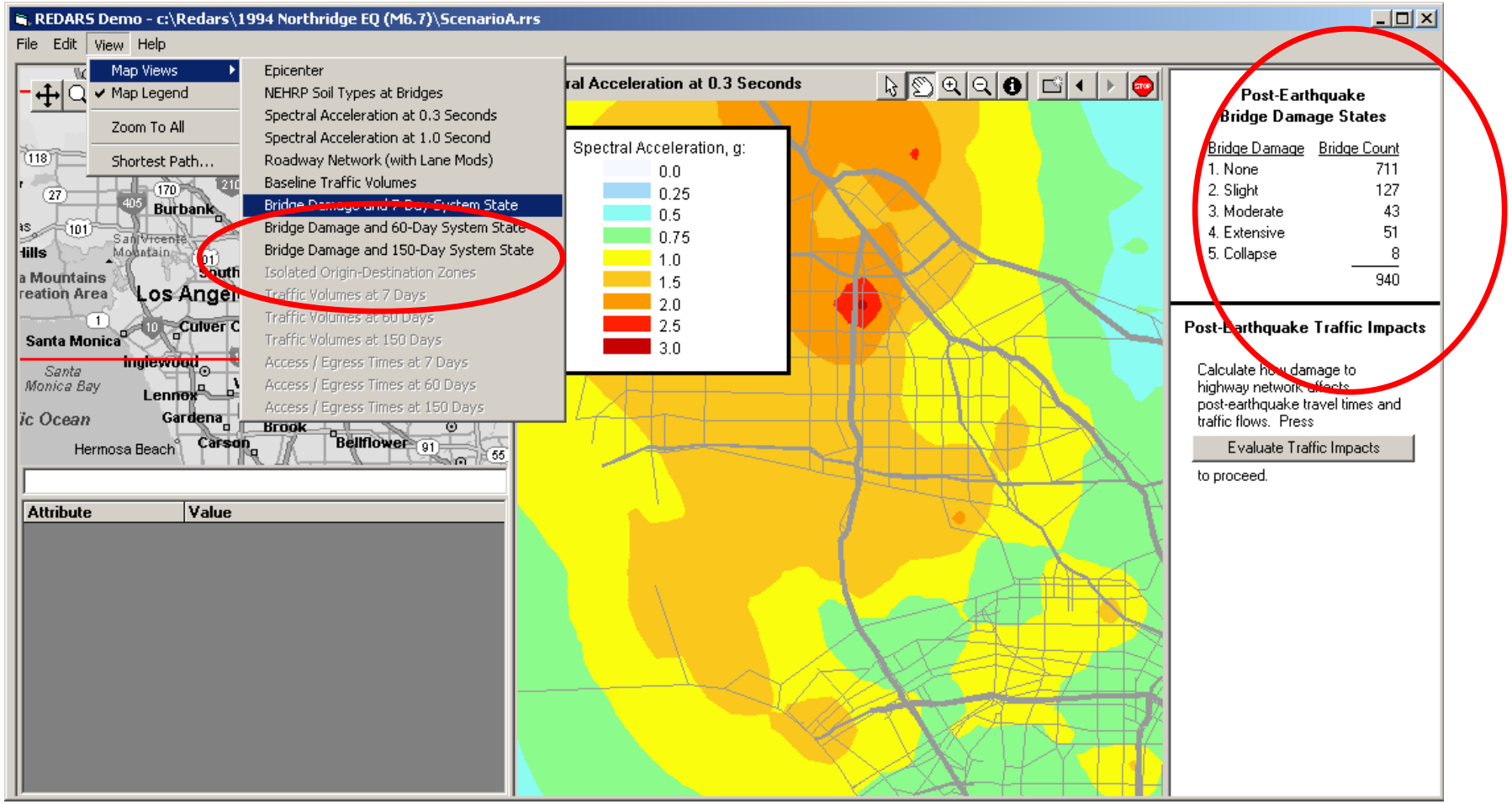
DIALOGUE BOX TO SELECT NORTHRIDGE EQ



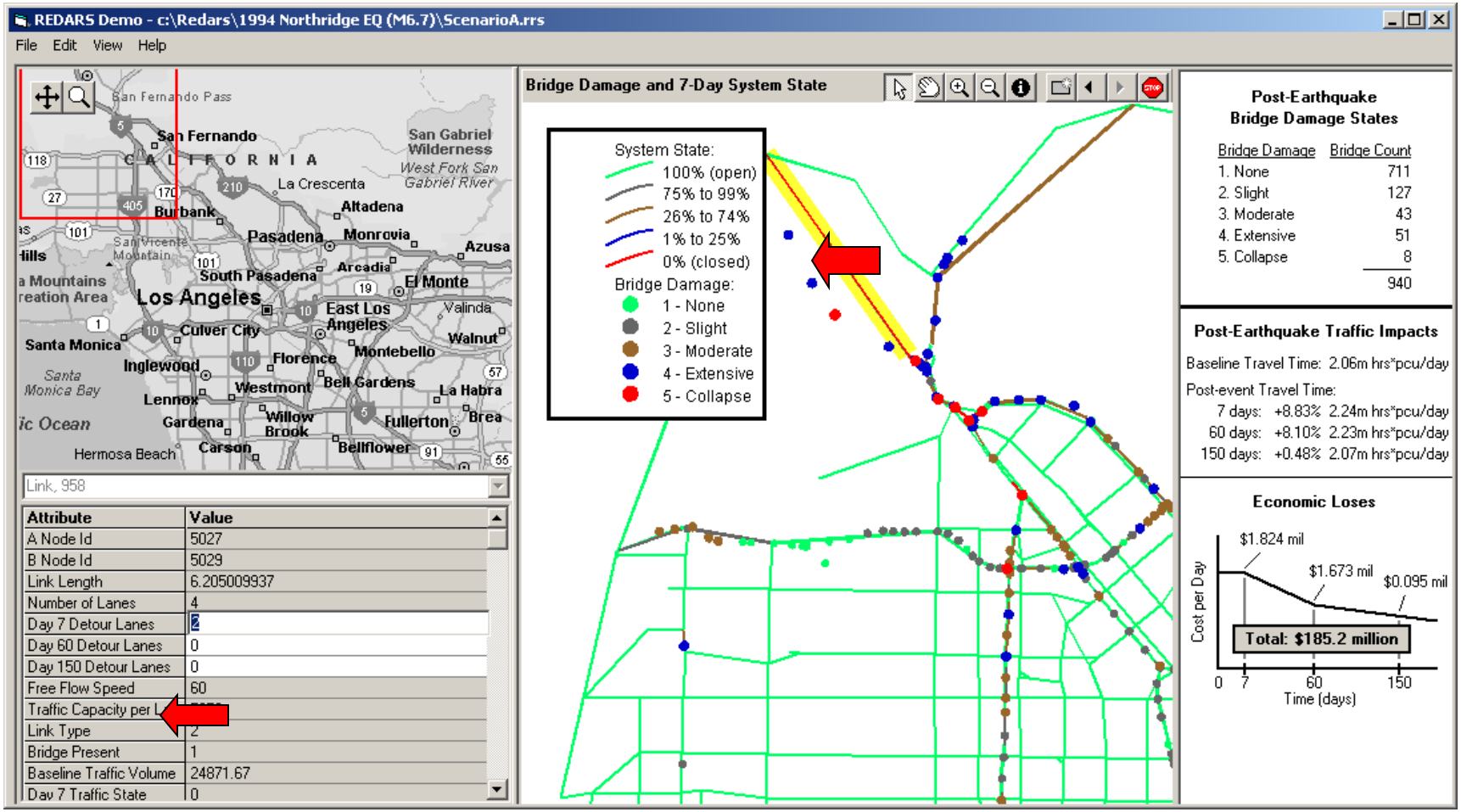
DROP-DOWN MENU:
ACCESS OF GROUND MOTION DATA



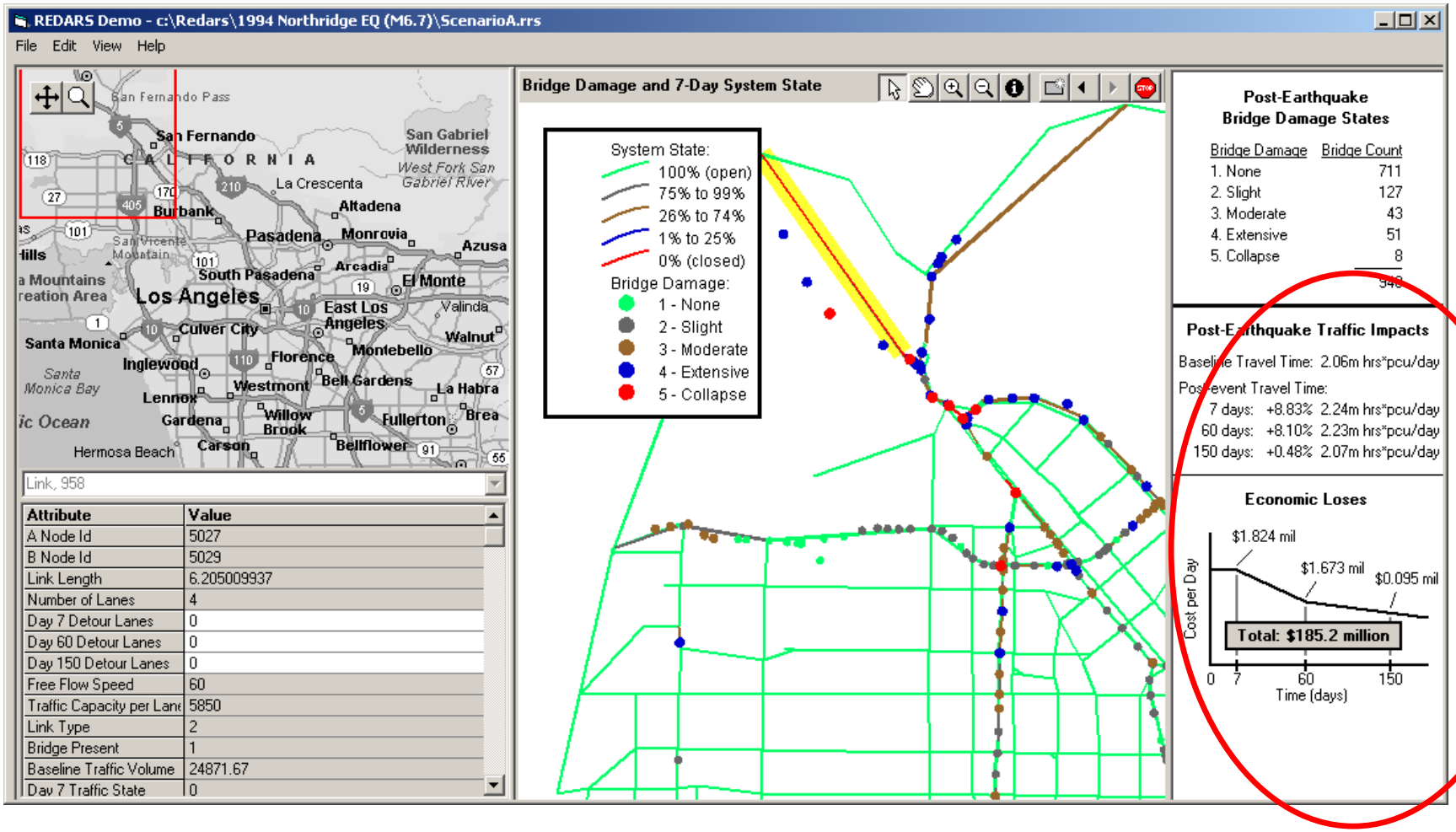
DROP-DOWN MENU: ACCESS BRIDGE DAMAGE & SYSTEM STATE DISPLAYS



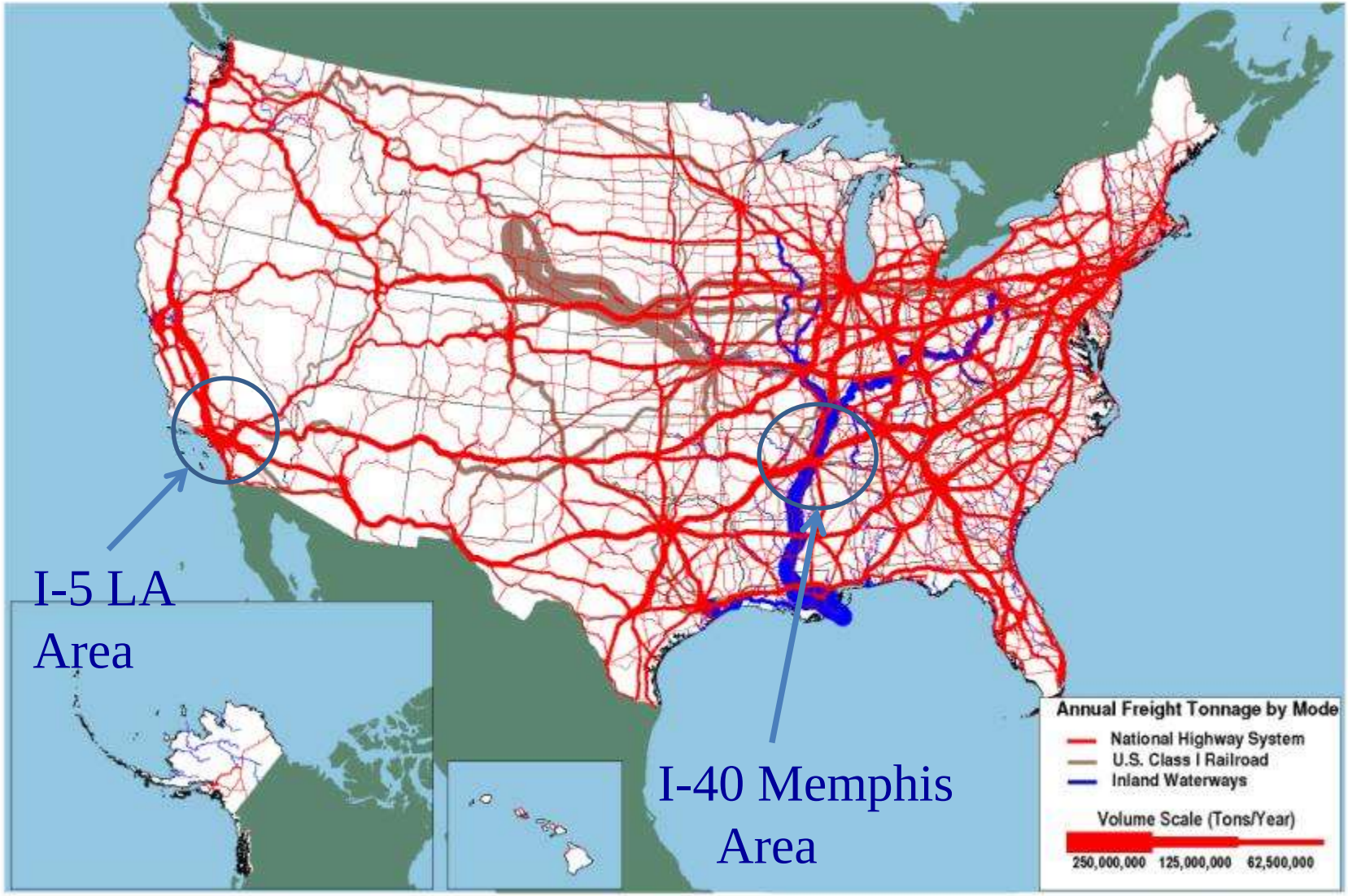
REAL-TIME ASSESSMENT OF ALTERNATIVE EMERGENCY RESPONSE STRATEGIES: (ADD DETOUR LINK ALONGSIDE DAMAGED BRIDGE)



AFTER NETWORK ANALYSIS:
TRAVEL TIME & ECONOMIC LOSS DISPLAY



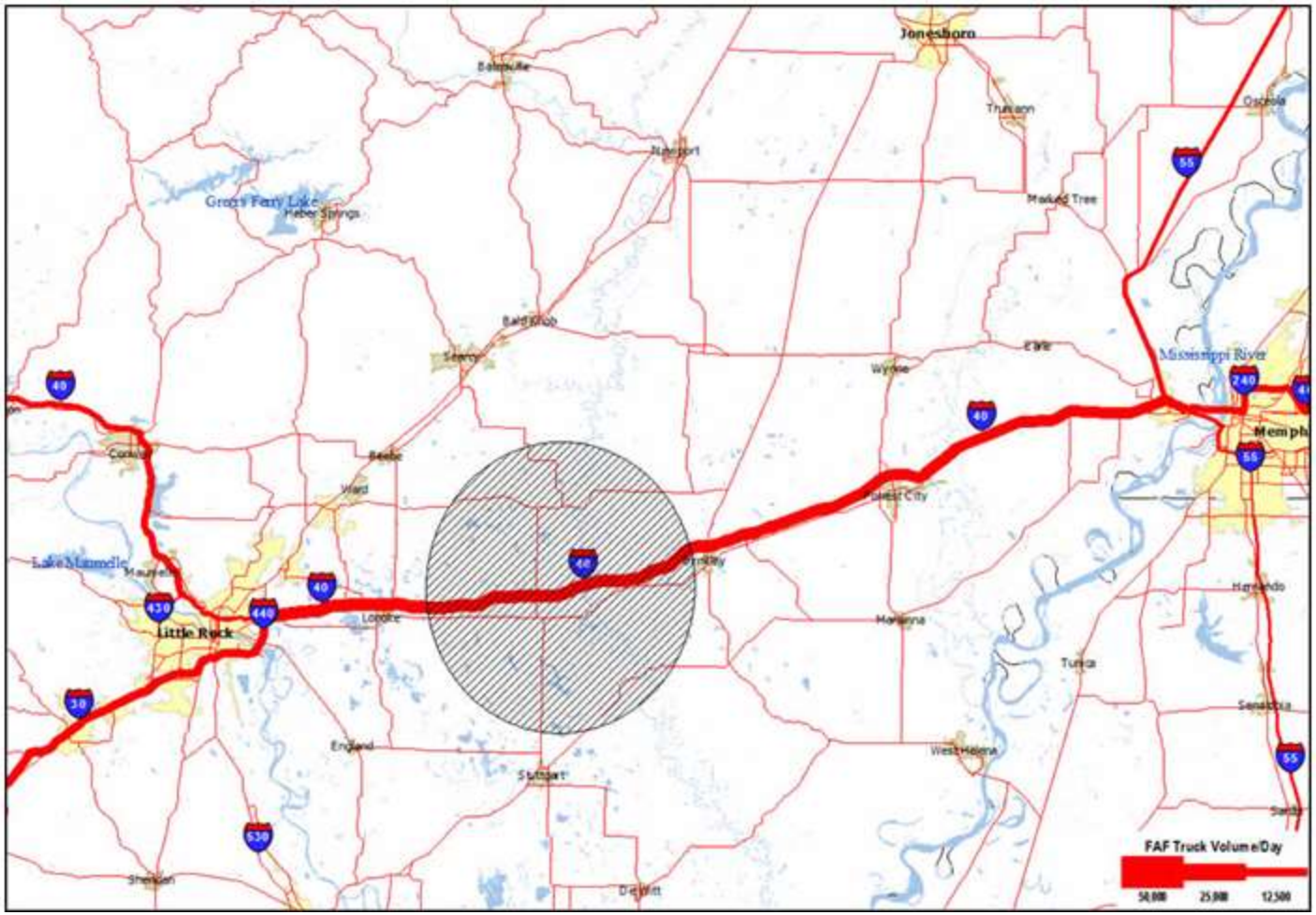
Tonnage on Highways, Railroads, and Inland Waterways: 2007



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 asssignments done by Oak Ridge National Laboratory.

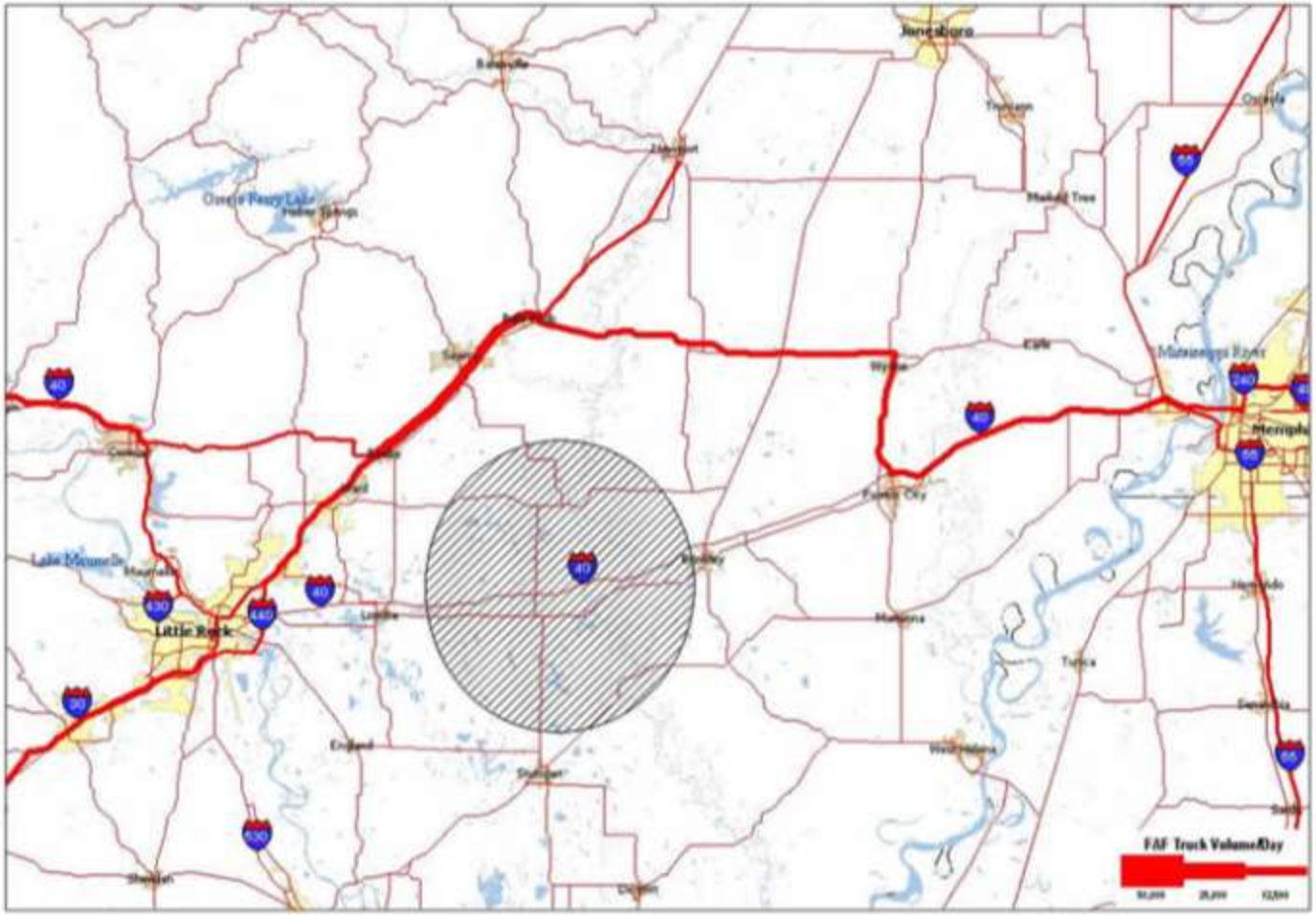
Freight Disruptions
Mississippi River Flooding

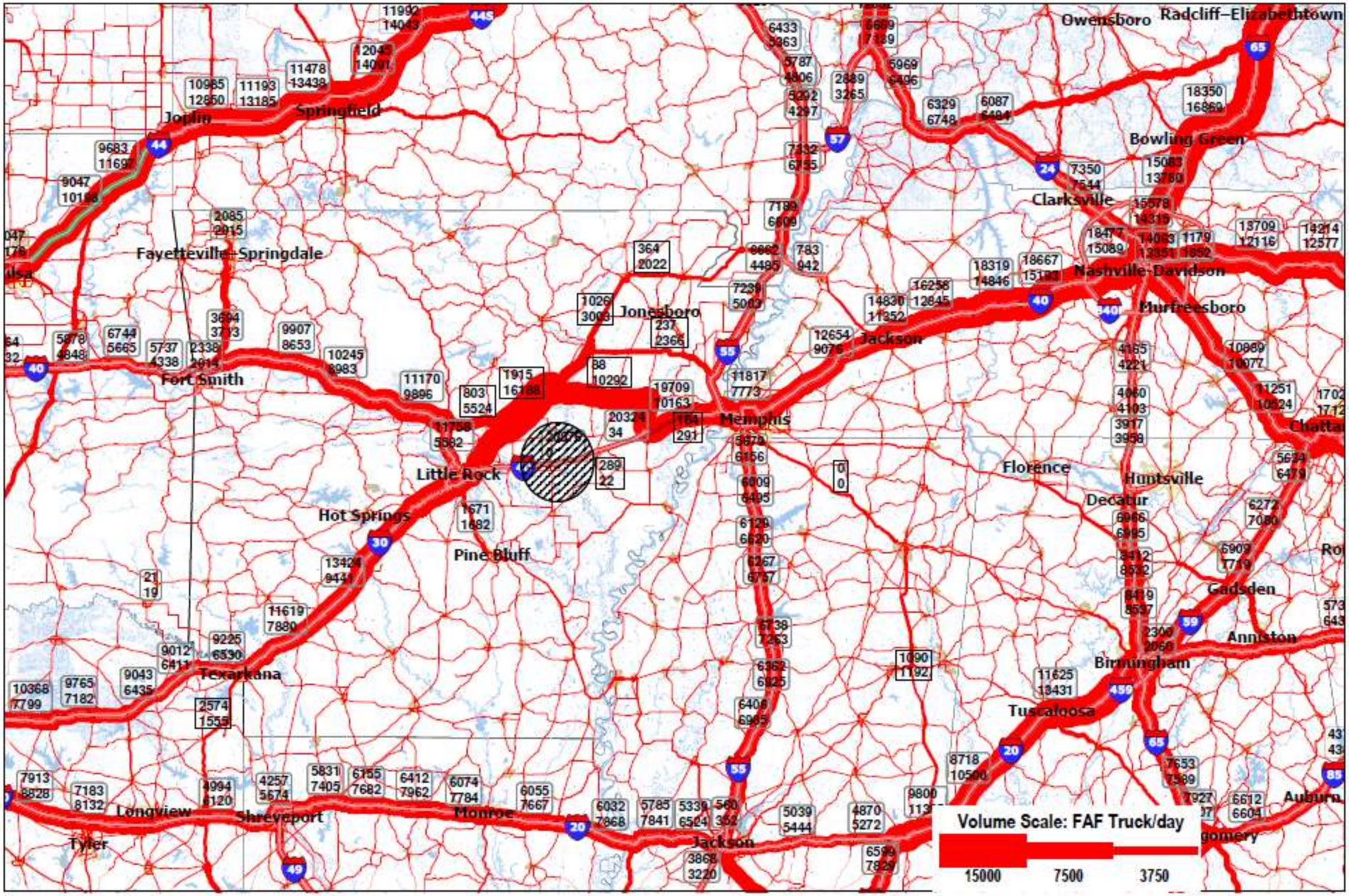
Pre-scenario Local I-40 Truck Flow Map



Freight Disruptions
Mississippi River Flooding

Post-scenario Local I-40 Truck Flow Map





Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.1.1, 2011.

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	Map
Liq. PGD:	0.00in	Map
SFR PGD:	0.00in	Map

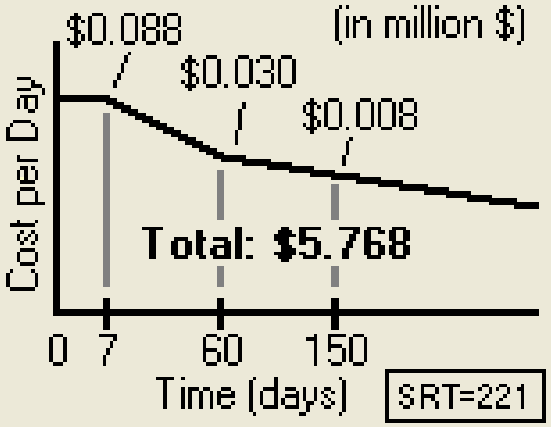
Component Damage

	Bridge	ApFill	Tunl	Pvmt
1. None	1575	3014	1319	462
2. Slight	41	288	0	0
3. Moderate	28	126	0	0
4. Extensive	54	0	0	0
5. Complete	33	0	0	0
Map	1731	3428	1319	462

Travel Impacts
(reduction relative to baseline)

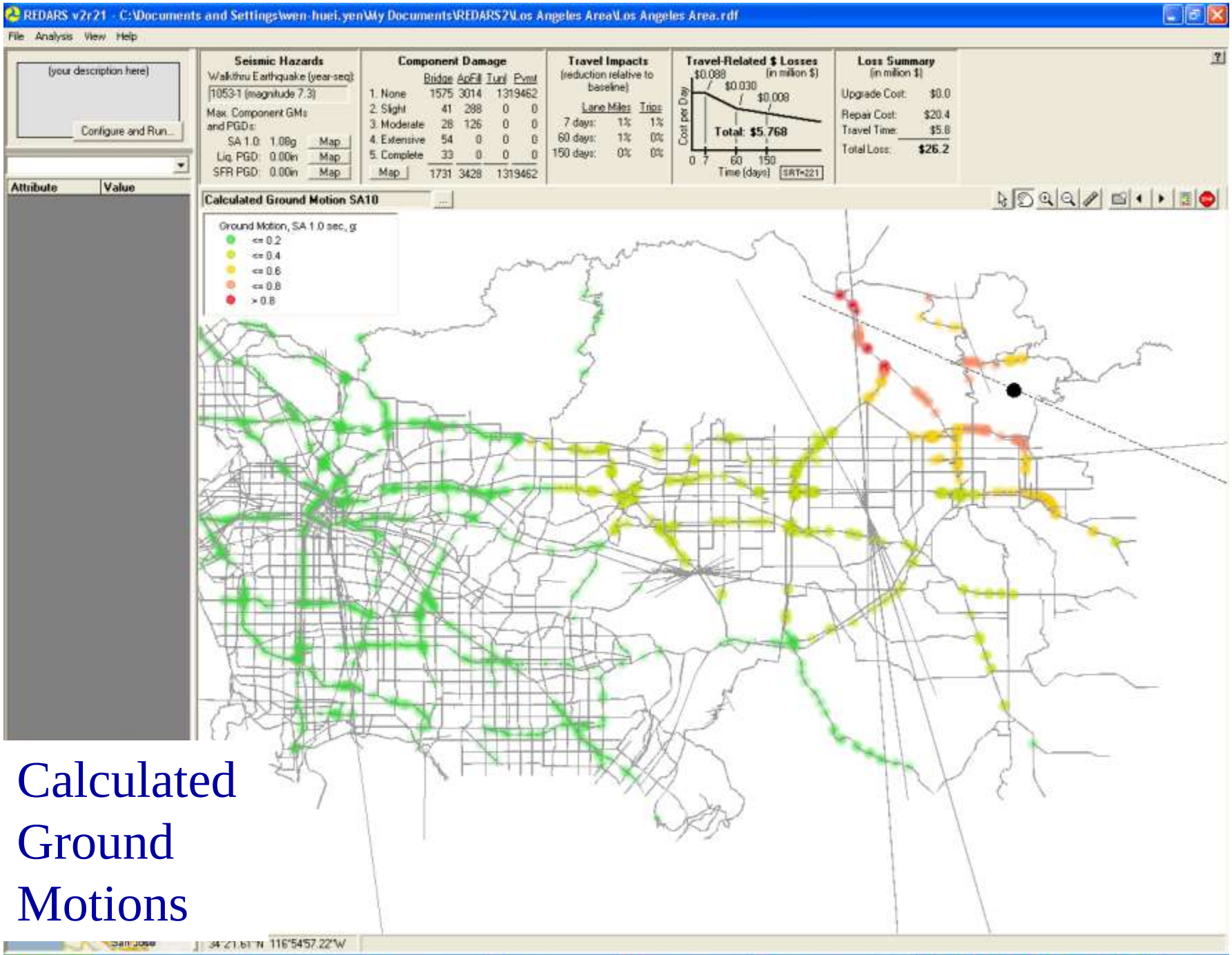
	Lane Miles	Trips
7 days:	1%	1%
60 days:	1%	0%
150 days:	0%	0%

Travel-Related $ Losses
(in million $)

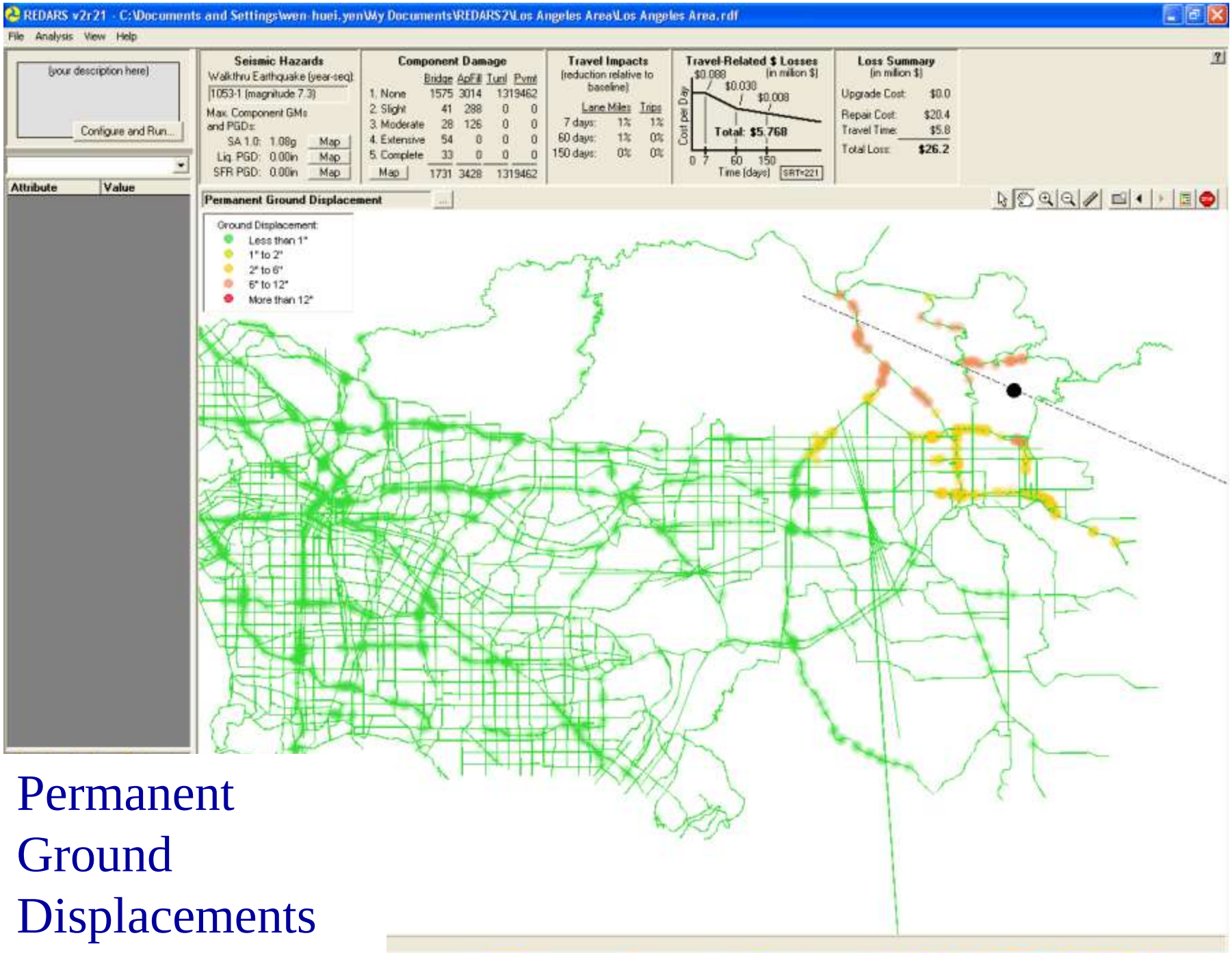


Loss Summary
(in million $)

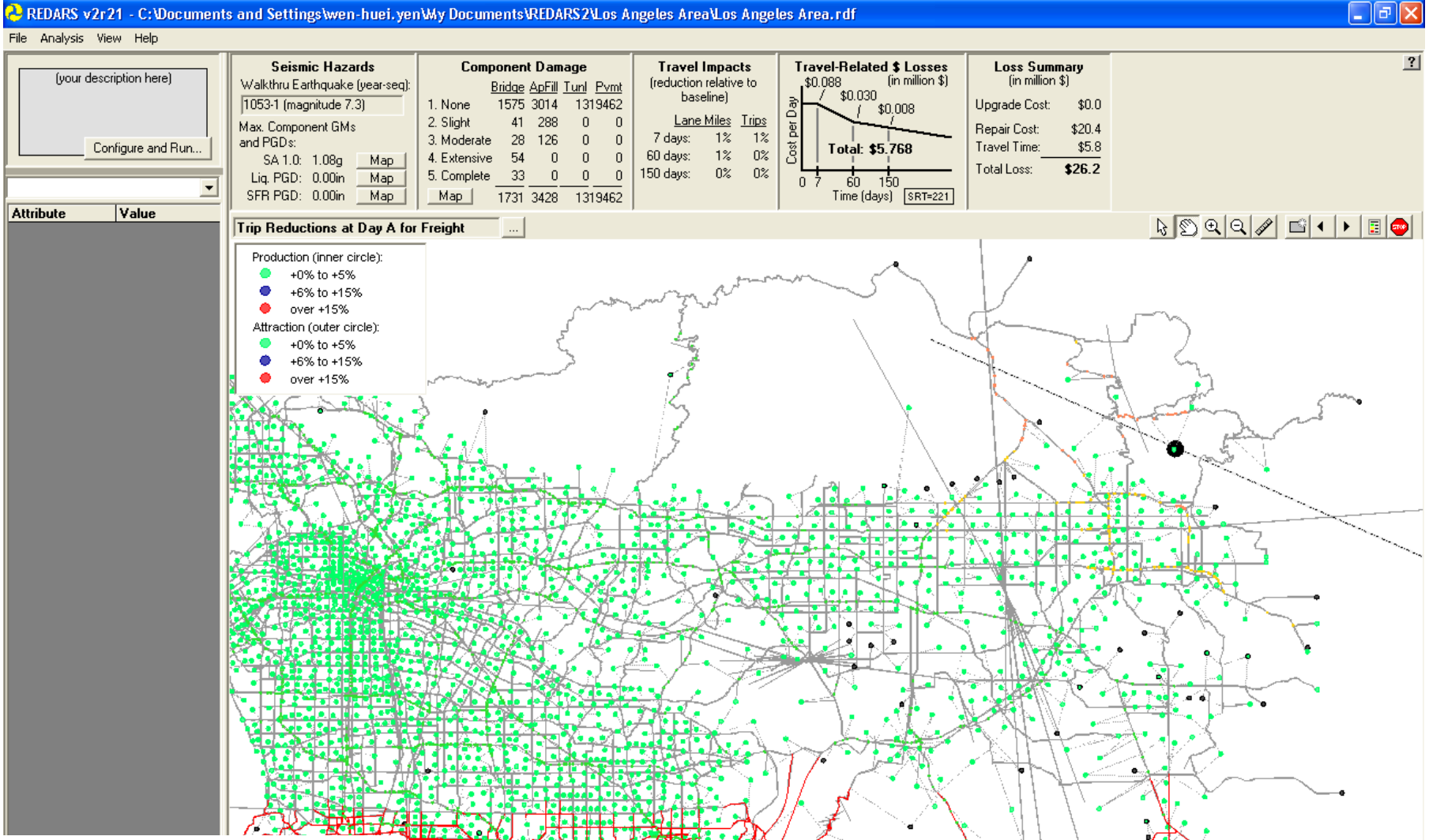
Upgrade Cost:	$0.0
Repair Cost:	$20.4
Travel Time:	$5.8
Total Loss:	**$26.2**



Calculated Ground Motions

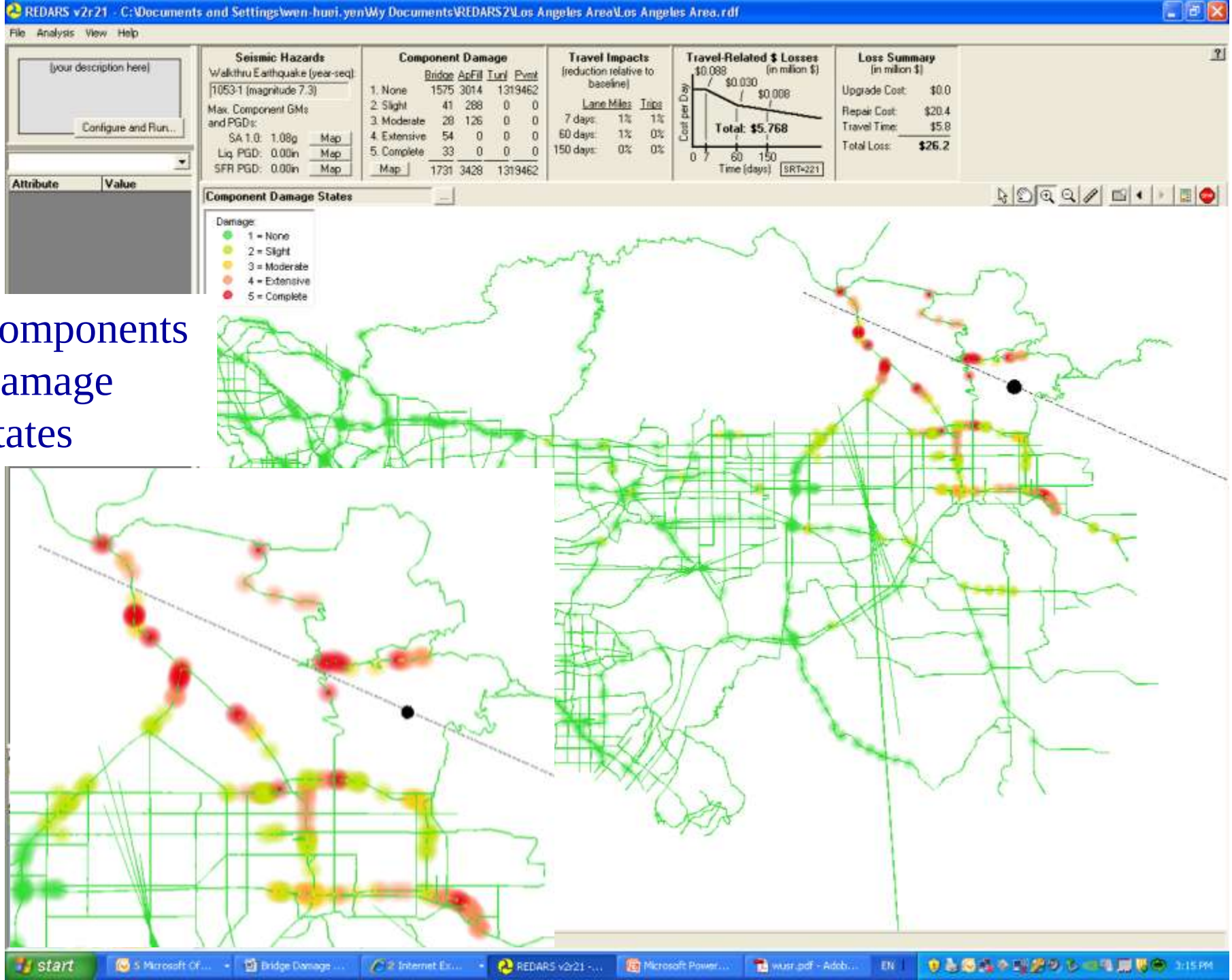


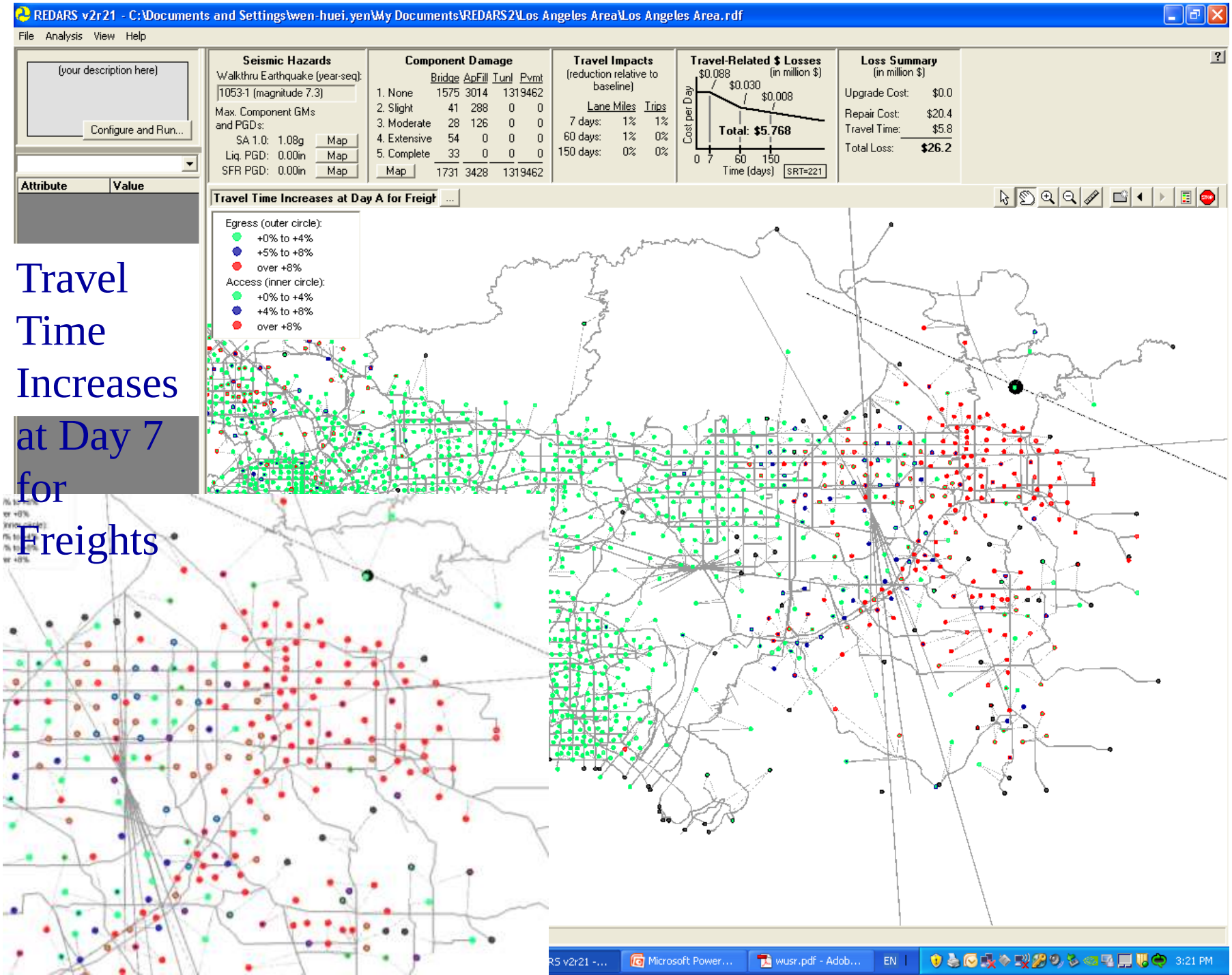
Permanent Ground Displacements



Trip Reductions at Day 7 for Freights

Components Damage States





Travel Time Increases at Day 7 for Freights

Damage and Loss Summary w/ 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	Map
Liq. PGD:	0.00in	Map
SFR PGD:	0.00in	Map

Component Damage

	Bridge	ApFill	Tunl	Pvmt
1. None	1486	2532	1319	462
2. Slight	119	896	0	0
3. Moderate	60	0	0	0
4. Extensive	46	0	0	0
5. Complete	20	0	0	0
Map	1731	3428	1319	462

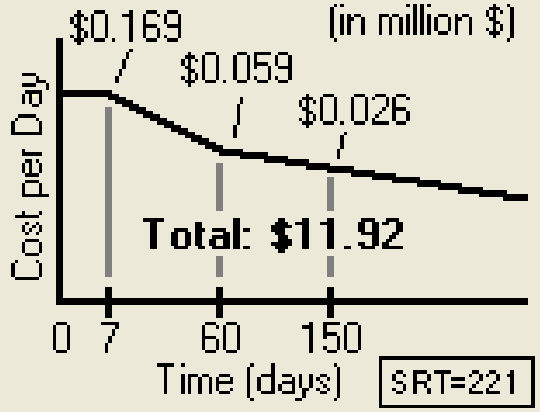
Travel Impacts

(reduction relative to baseline)

	Lane Miles	Trips
7 days:	2%	4%
60 days:	1%	1%
150 days:	0%	0%

Travel-Related $ Losses

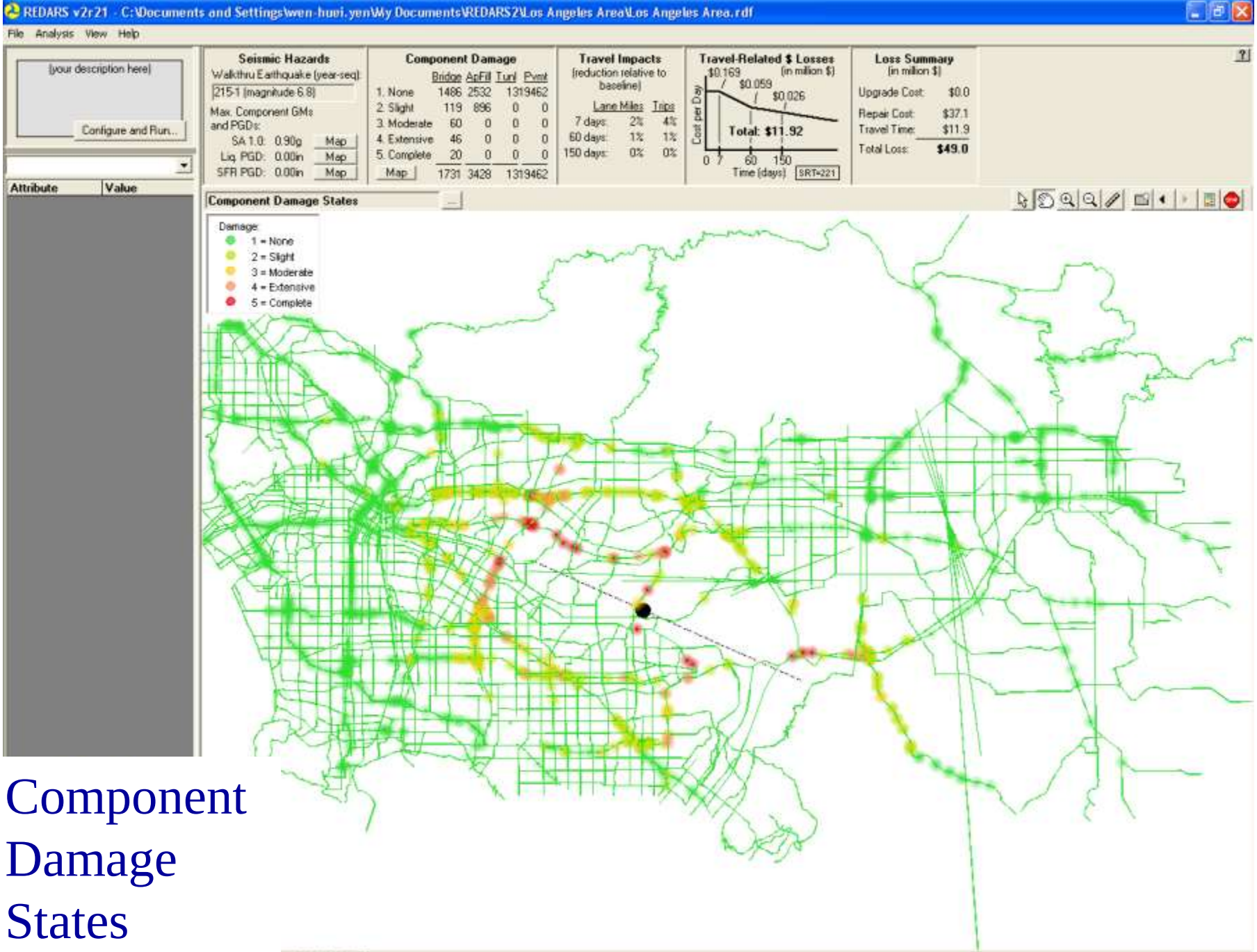
(in million $)



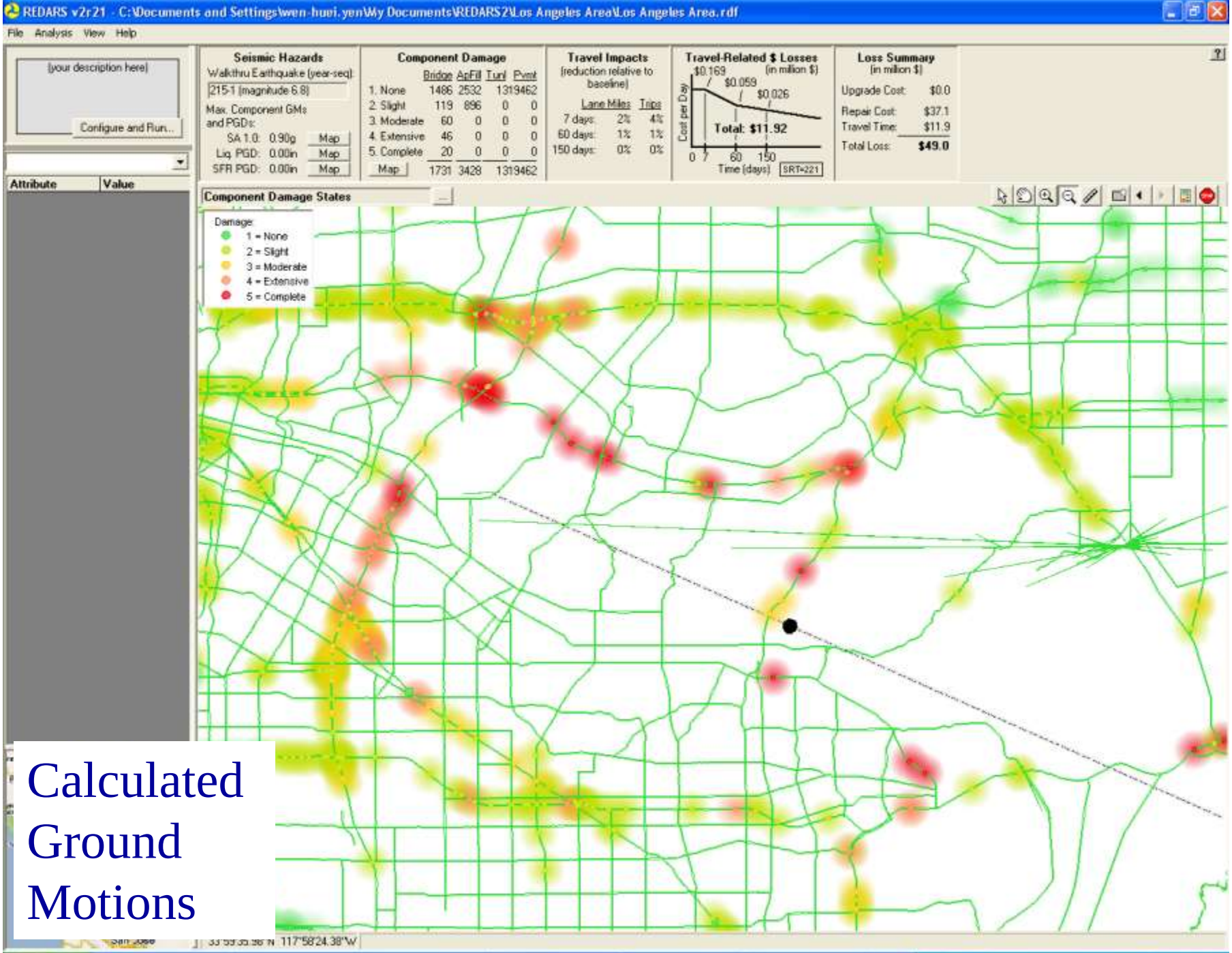
Loss Summary

(in million $)

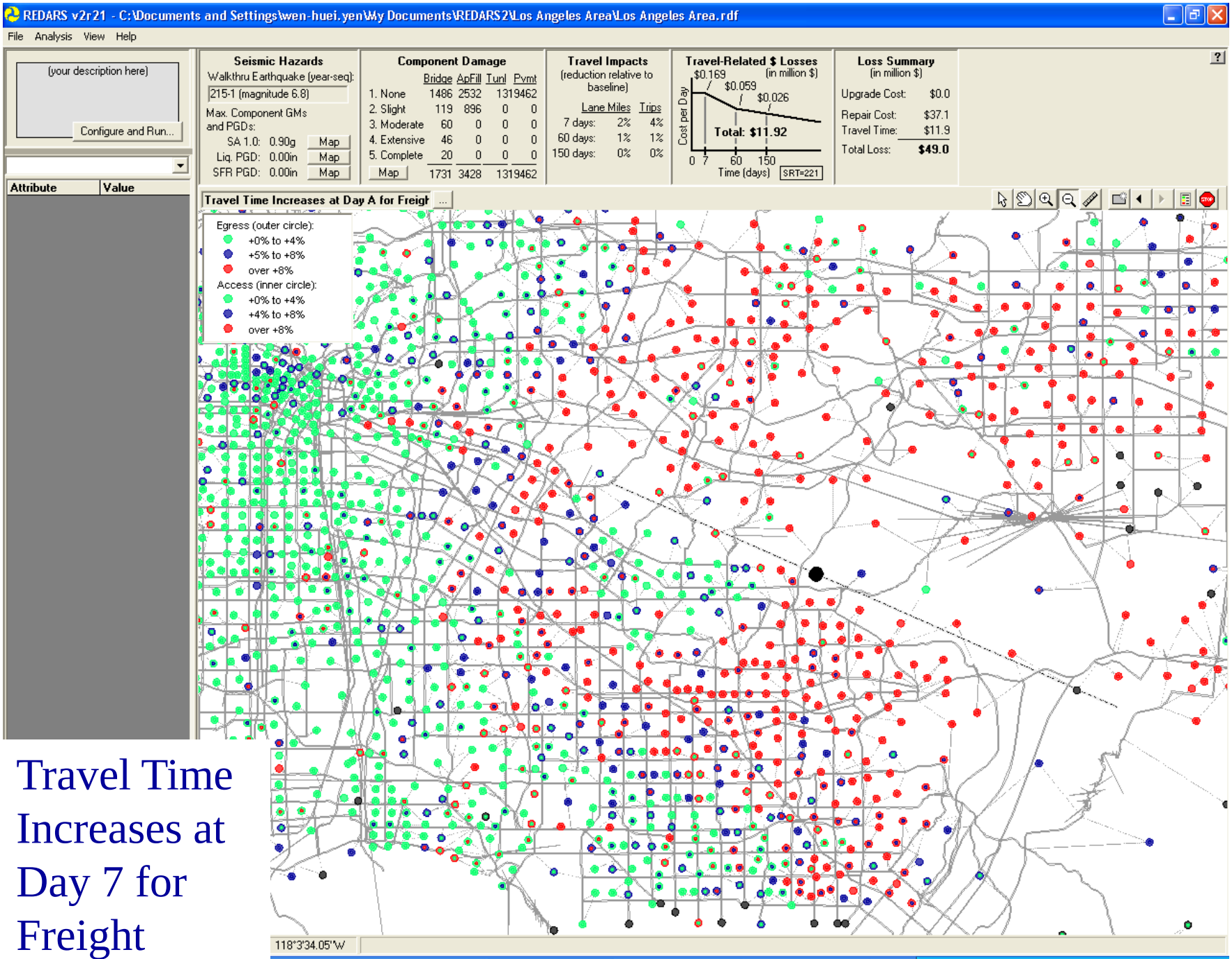
Upgrade Cost:	$0.0
Repair Cost:	$37.1
Travel Time:	$11.9
Total Loss:	**$49.0**



Component Damage States



Calculated Ground Motions



Travel Time Increases at Day 7 for Freight

Average National Daily FAF Truck VMT: 2007

Before Damage	After Damage	Difference	
5,835,180,871	5,852,841,251	17,660,379	

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

Before Damage	After Damage	Difference	
105,033,255,678	105,351,142,518	317,886,822	

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

Before Damage	After Damage	Difference	
$17,372,500,489	$17,425,078,972	$52,578,480	

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

http://www.fhwa.dot.gov/research/tfhrc/programs/safety/

Federal Highway Administration Research and Technology

Coordinating, Developing, and Delivering Highway Transportation Innovations

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

About | Expertise | Laboratories | Offices | Programs | Research Projects | Contact

Research Home

TFHRC Home

Federal Highway Administration > Research > TFHRC > Program > Safety Research and Development (R&D) Program

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.

Office of Safety R&D Links

- Office of Safety R&D
- Safety R&D Program
- Safety R&D Experts
- Safety R&D Laboratories
- Safety R&D Projects
- Safety R&D Publications
- Safety R&D Topics

Other Links

- FHWA's Office of Safety
- Resource Center Safety and Design Team

Human Factor Laboratory Open House

Dr. David Yang
David.yang@dot.gov
202-493-3284

Dr. Brian Philips
Brian.philips@dot.gov
202-493-3468

Thank you for your attention.

Questions?