Multi-hazard Preparedness & Risk Management of Highway Bridges -
An Example from Seismic Hazard Mitigation

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Federal Highway Administration

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Outline

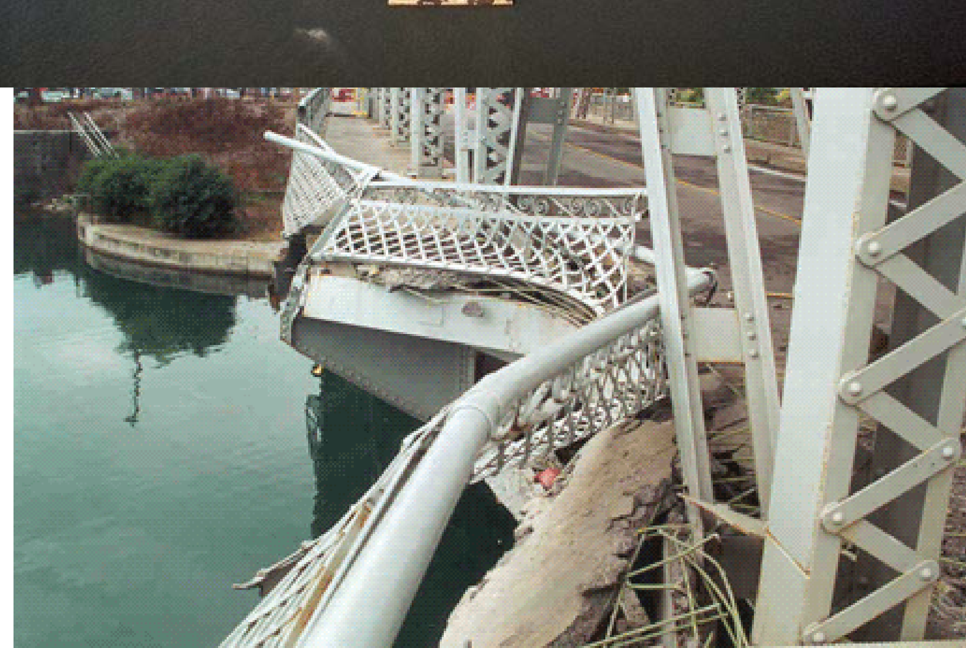
- Background
  - Bridge Asset Vs. Hazard Impacts
- Risk Management & Hazard Mitigation Preparedness
  - An Example from Seismic Hazard Mitigation
- Multi-hazard Design Criteria
- Summary

Bridge Structures Asset

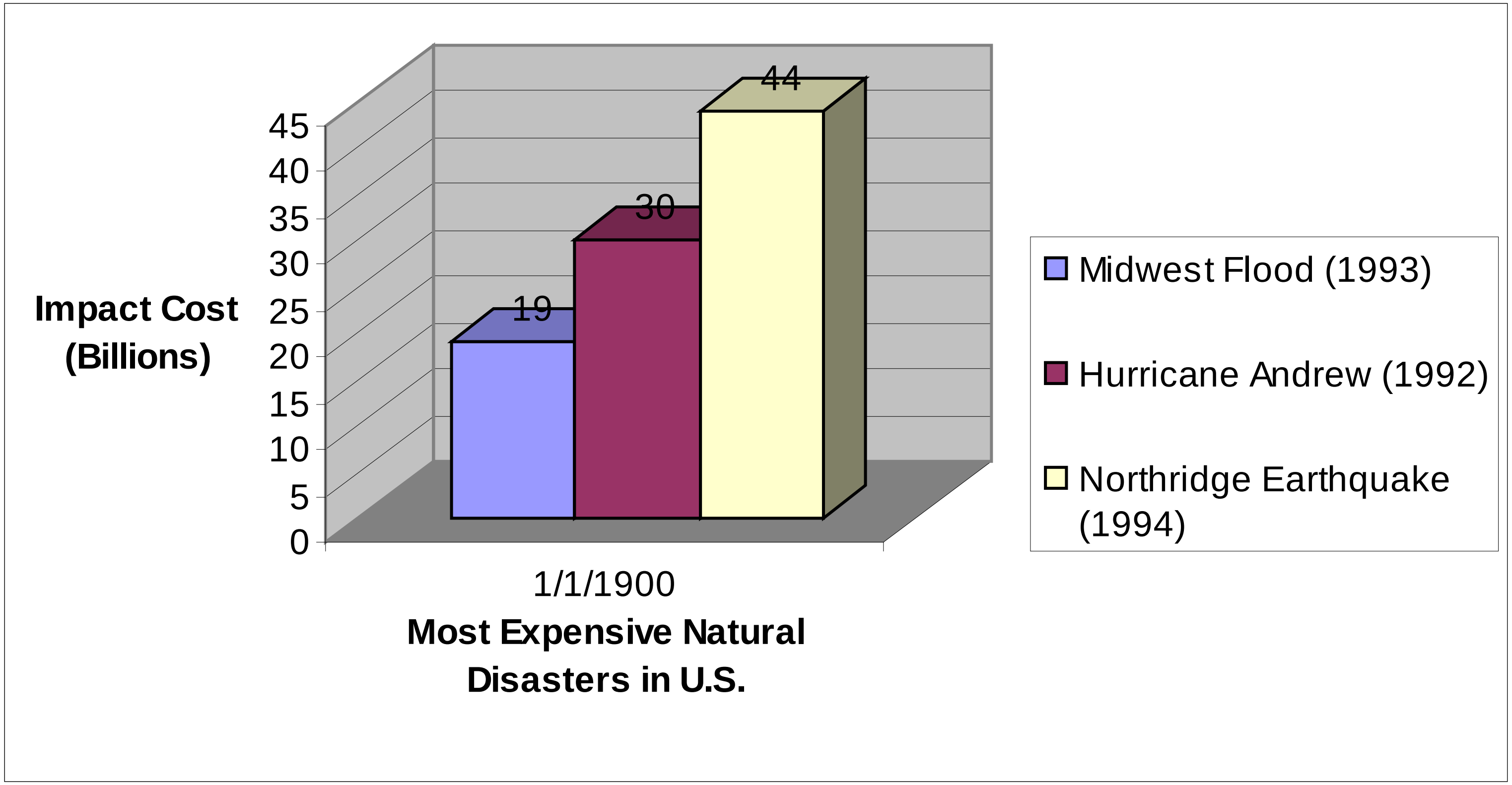
- ~ 600,000 Highway Bridges in the NBI Data
- ~ 300 Tunnels
- ~ 4,200,000 miles Roads

Natural & Man-made Hazards

- Earthquake
- Wind Storm
- Flood
- Vessel Collision



Impacts of Natural Hazards



DEFINITION OF TERMS

- Hazard
  - Likelihood of occurrence of a natural event in terms of it's maximum intensity
- Vulnerability
  - Weakness or fragility of roads/bridges against a natural event
- Risk
  - Quantitative expression of uncertainties and harmful consequences associated with a hazard

RISK MANAGEMENT

- Managing uncertainties and harmful consequences associated with a hazard

RISK MANAGEMENT

- Identify The Hazard
- Identify Vulnerability & Consequences
- Identify Mitigating Solutions / Strategies
- Optimize Benefits of Mitigation Strategies

RISK MANAGEMENT

- Identify the Hazard
  - Type
  - Likelihood of Occurrence
  - Intensity / Severity
  - Location / Time

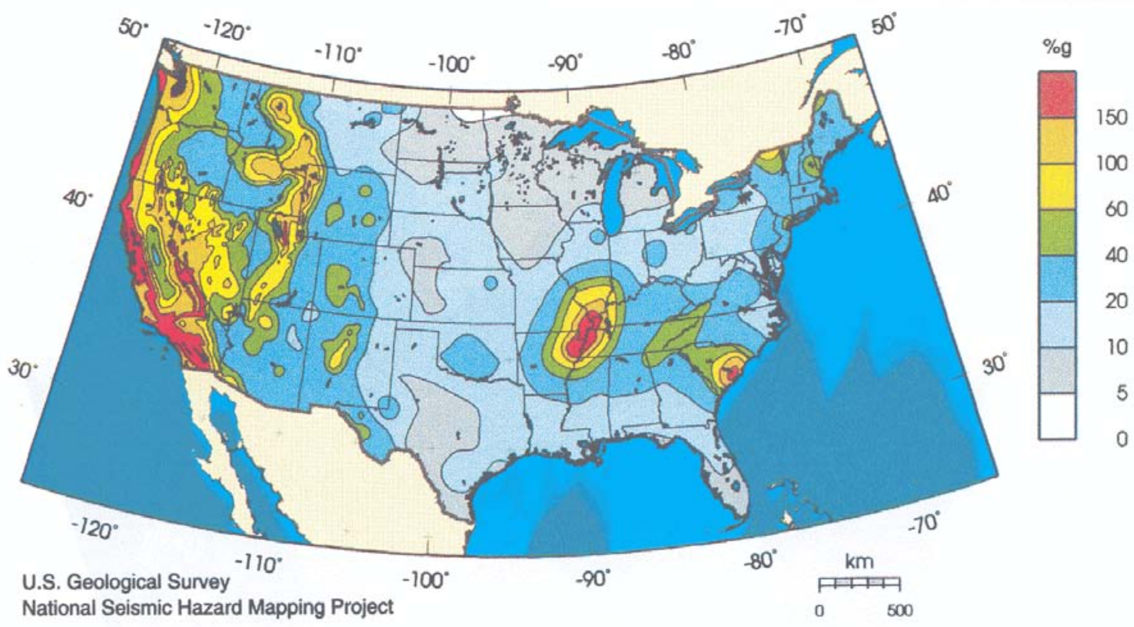


Figure 9a. MCE ground motion map of the 48 conterminous states for the 0.2 sec horizontal spectral response acceleration (%g), 5% of critical damping, Site Class B.

RISK MANAGEMENT

- Identify the Hazard
- Identify Vulnerability

& Consequences

RISK MANAGEMENT

- Identify the Hazard
- Identify Vulnerability & Consequences
- Identify Mitigating Solutions / Strategies
  - Preparedness
  - Control
  - Design
  - Retrofit

RISK MANAGEMENT

- Identify The Hazard
- Identify Vulnerability & Consequences
- Identify Mitigating Solutions / Strategies
- Optimize Benefits of Mitigation Strategies
  - Cost
  - Lost Opportunity
  - Life safety
  - Serviceability

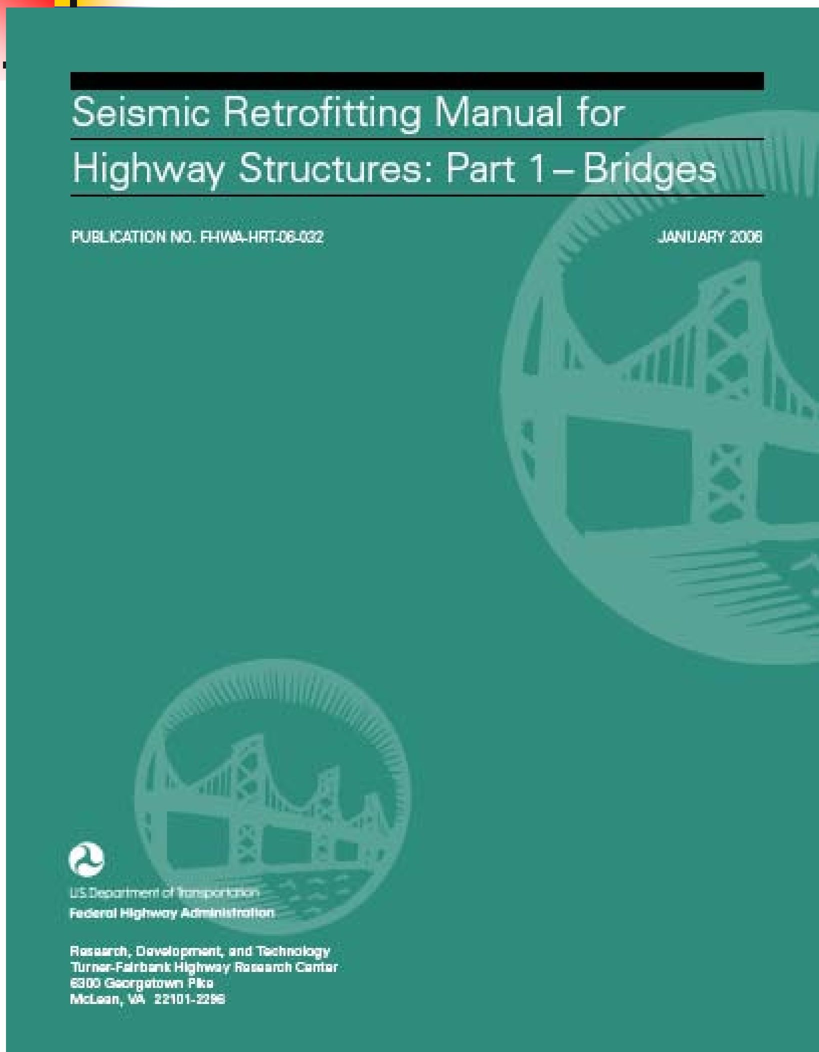
DESIGN

- Pre-San Fernando
  - 0.06g Static Coefficient
  - No Consideration For
    - Spectral Response
    - Foundation Material
    - Structural Ductility
- Today
  - Seismic Performance Criteria Identified

RETROFIT

- Pre-San Fernando
  - None
- Today, 3 Classes of Retrofit
  - A. Standard higher than for new construction
  - B. Same standard as for new construction
  - C. Standard lower than for new construction
- C-Class Predominantly Used

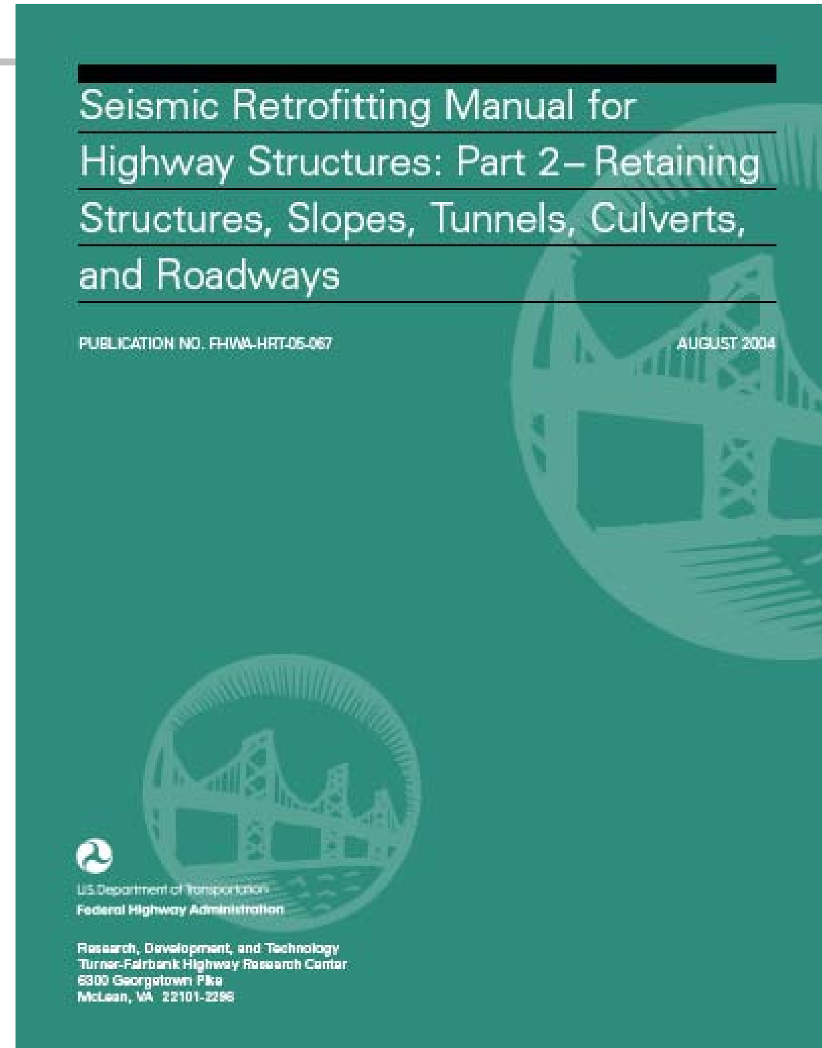
NEW FHWA Seismic Retrofitting Manuals


Seismic Retrofitting Manual for
Highway Structures: Part 1 – Bridges

PUBLICATION NO. FHWA-HRT-06-032 JANUARY 2006

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296


Seismic Retrofitting Manual for
Highway Structures: Part 2 – Retaining
Structures, Slopes, Tunnels, Culverts,
and Roadways

PUBLICATION NO. FHWA-HRT-05-067 AUGUST 2004

U.S. Department of Transportation
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Performance levels for bridge retrofitting

EARTHQUAKE	BRIDGE IMPORTANCE and SERVICE LIFE					
	Standard			**Essential**		
	ASL1	ASL2	ASL3	ASL1	ASL2	ASL3
Lower Level	PL0	PL3	PL3	PL0	PL3	PL3
Upper Level	PL0	PL1	PL1	PL0	PL1	PL2

LESSONS LEARNED SINCE SAN FERNANDO

- New Design Perform Well
- Retrofit Works



Significant Earthquake Damages in the U.S. 1964-2001

Location	Date	Magnitude	Damages (in Millions)	Deaths
Prince William Sound, AK	03/27/1964	8.4	$311.0	125
San Fernando, CA	02/09/1971	6.6	$505.0	65
Loma Prieta, CA	10/17/1989	7.1	$6,000.0	63
Northridge, CA	01/17/1994	6.7	$20,000.0	61
Nisqually, WA	02/28/2001	6.8	$2,100.0	1

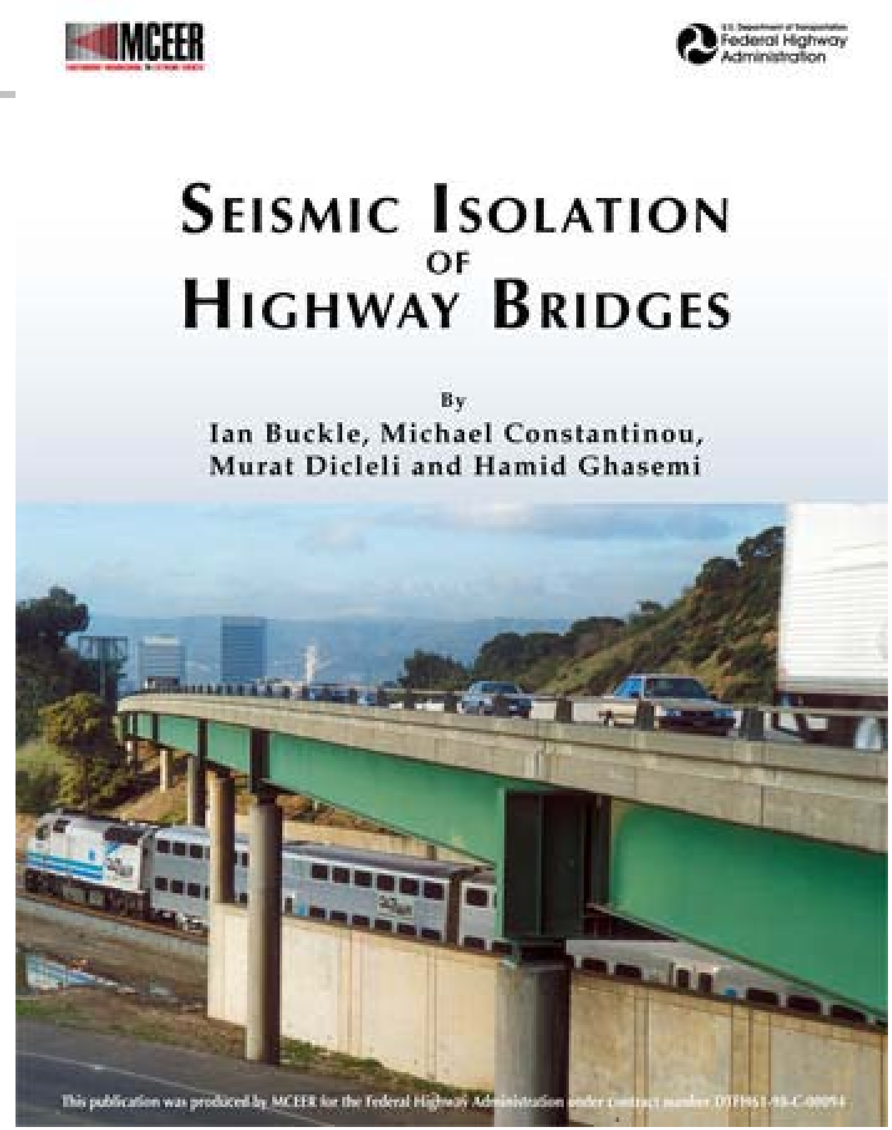
TYPICAL RETROFITS

- Displacement Control
  - Bearings
  - Thermal expansion joints
- Force Control
  - Columns
  - Foundations

Seismic Isolation of Highway Bridges

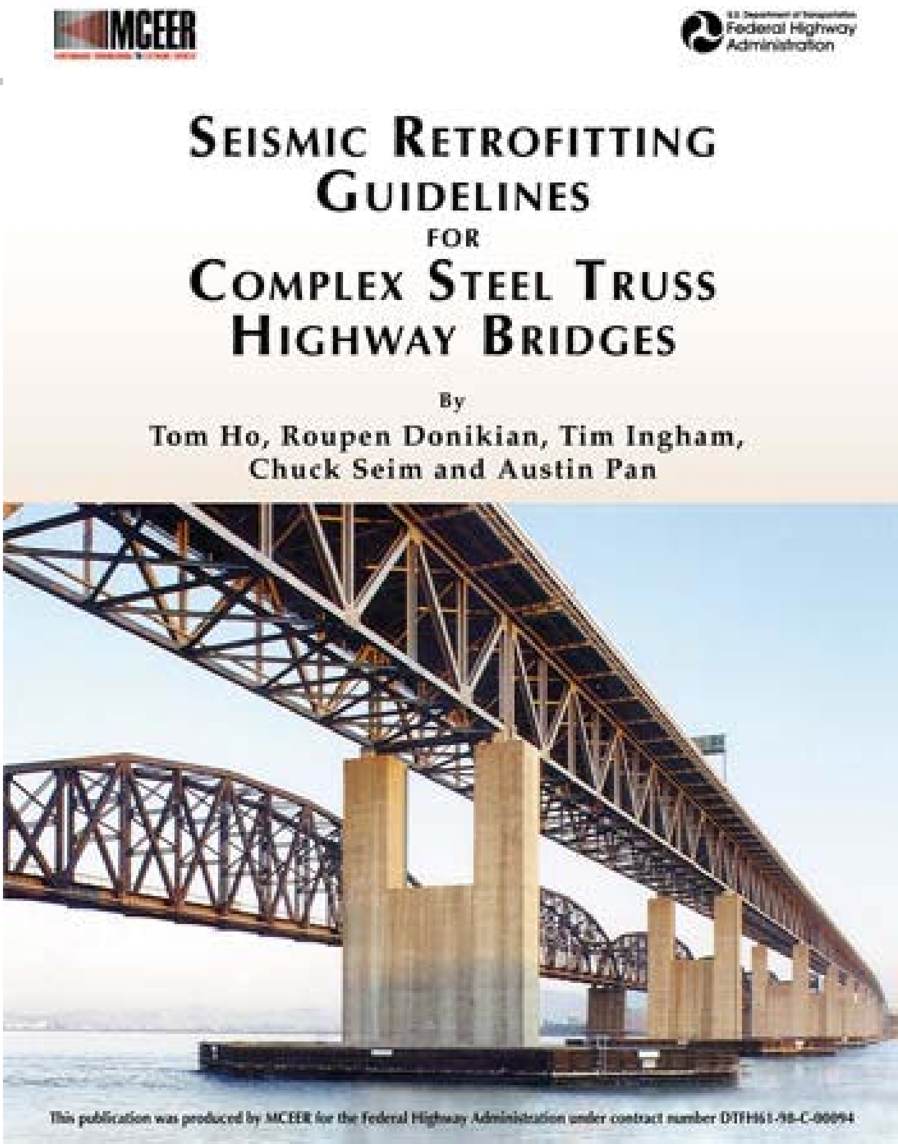
- **I.G. Buckle, M. Constantinou, M. Dicleli and H. Ghasemi**

- *Seismic Isolation of Highway Bridges* presents the principles of isolation for bridges, develops step by step methods of analysis, explains material and design issues for elastomeric and sliding isolators, and gives detailed examples of their application to standard highway bridges. The manual is a supplement to the *Guide Specifications for Seismic Isolation Design* published by AASHTO in 1999.



Seismic Retrofitting Guidelines for Complex Steel Truss Highway Bridges

- **T. Ho, R. Donikian, T. Ingham, C. Seim and A. Pan**
- A performance-based seismic retrofit philosophy is used. The guidelines cover all major aspects pertinent to the seismic retrofitting of steel truss bridges, with a focus on superstructure retrofit. Case studies are provided.
  These guidelines are a supplement to the *2006 FHWA Seismic Retrofitting Manual for Highway Structures* for “unusual or “long span” steel trusses.



PLANNING - Seismic Performance Criteria

- For Uniform Seismic Risk
- Define Expected Behavior
  - Realistic ground motion intensity and forces used in design
  - Small to moderate earthquakes resisted within elastic range
    - Minimal damage
  - Avoid collapse during large earthquake
  - Damage readily detectable

PLANNING - Seismic Performance Criteria

- Implies Equal Probability of Exceedence
  - LRFD
    - 10% Probability in 50 year exposure (475 yr.)
  - 2007 New Guide Spec.
    - 7% Probability in 75 year exposure (~ 975 yr.)

PLANNING PREPAREDNESS

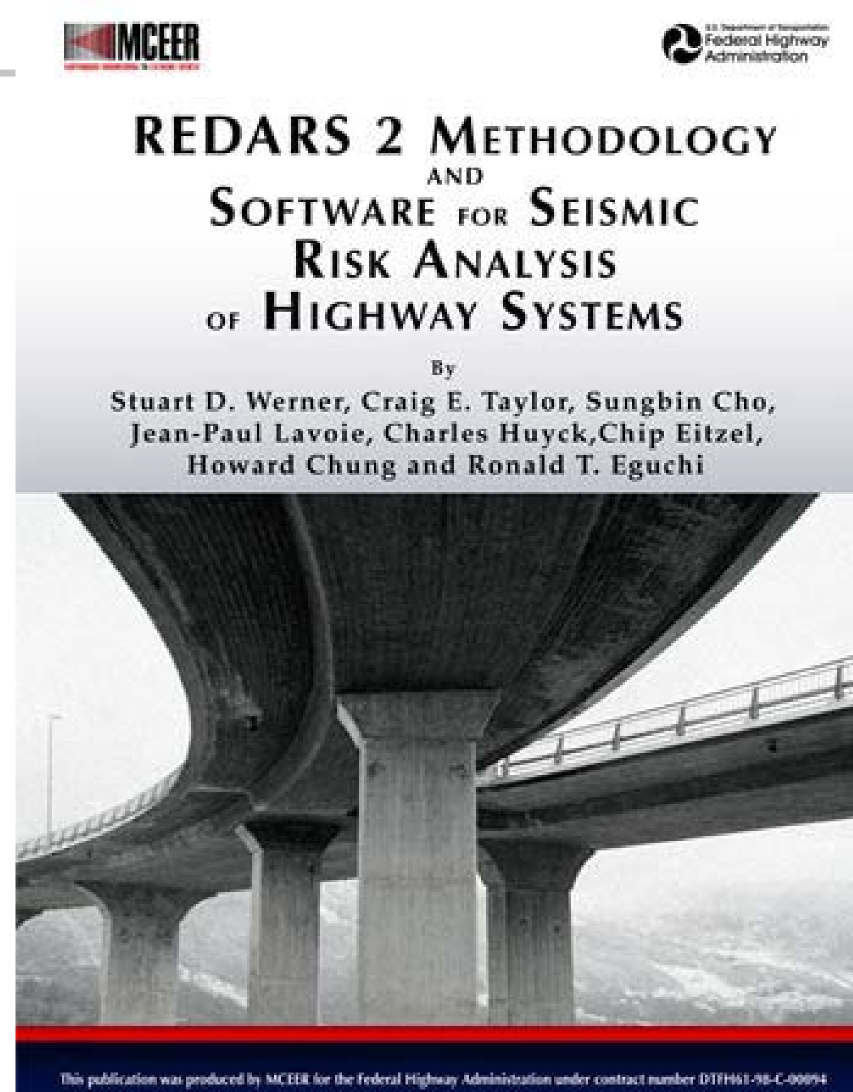
- Emergency Response Goals
  - Protect public safety
  - Protect / preserve the inventory
  - Reopen system ASAP
- Owner Assures Well Trained staff
  - Dedicated
  - Willing to sacrifice
  - Empowered to make decisions
  - Knowledgeable of assigned area of responsibility

PLANNING PREPAREDNESS

- Emergency Operations Center Established at Site
- Practice
  - Routine (annual) exercise
- Real-Time Communications
  - Direction
  - Reports

REDARS 2: Methodology and Software for Seismic Risk Analysis of Highway Systems

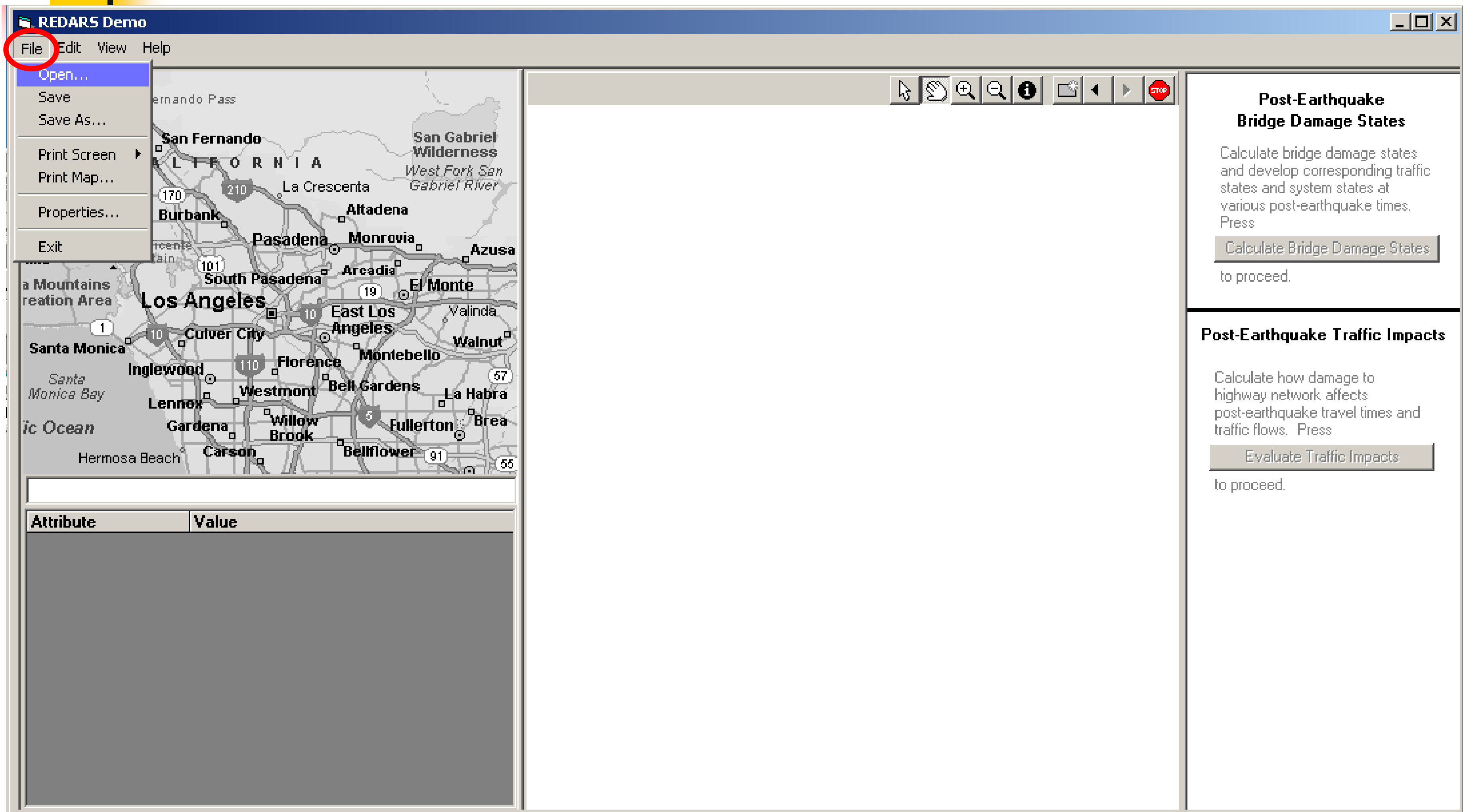
- **S.D. Werner, C.E. Taylor, S. Cho, J-P. Lavoie, C. Huyck, C. Eitzel, H. Chung and R.T. Eguchi**
- The REDARS 2 report provides the basic framework and a demonstration application of the Seismic Risk Analysis (SRA) methodology and its modules. The main modules of the REDARS 2 SRA methodology include hazards, components, system and economic. The northern Los Angeles, California highway system is used as a demonstration application of the SRA methodology.



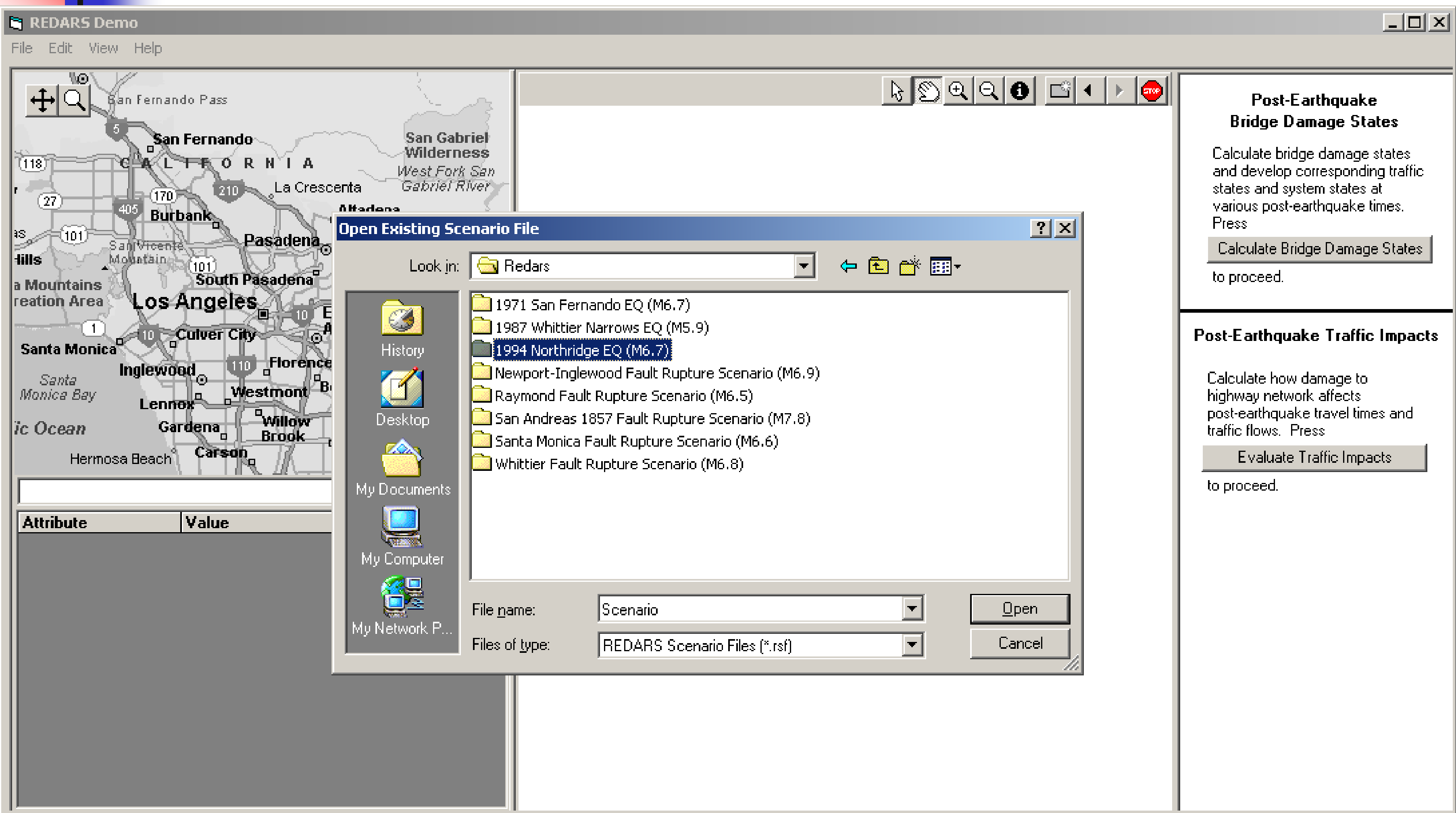
REDARS SOFTWARE: DESCRIPTION

- A Systematic Approach based on Loss Estimation
- Pre-EQ.
  - Loss Estimation
  - Emergency Planning
- Post-EQ.
  - Emergency Dissemination

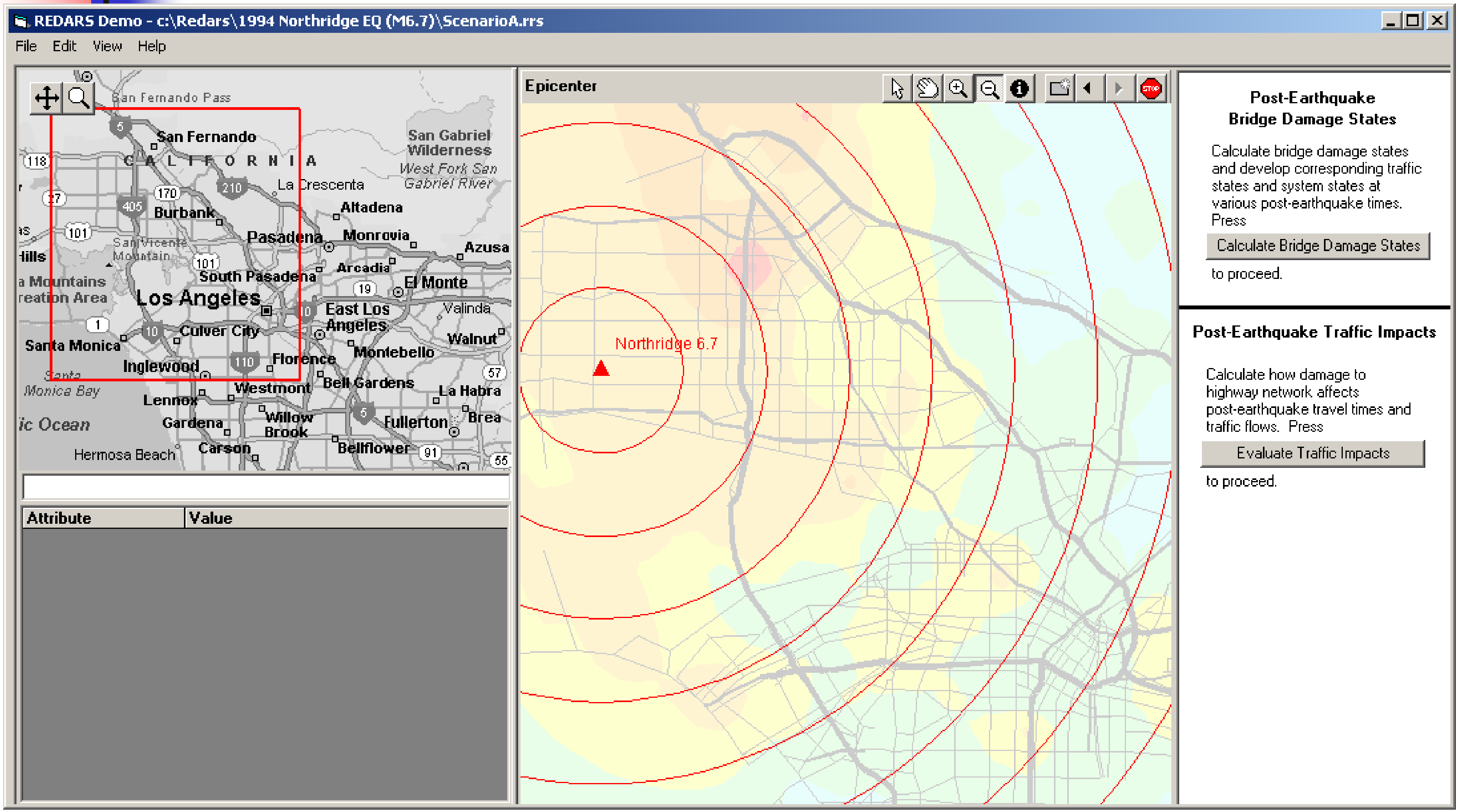
OPENING OF REDARS 1.0



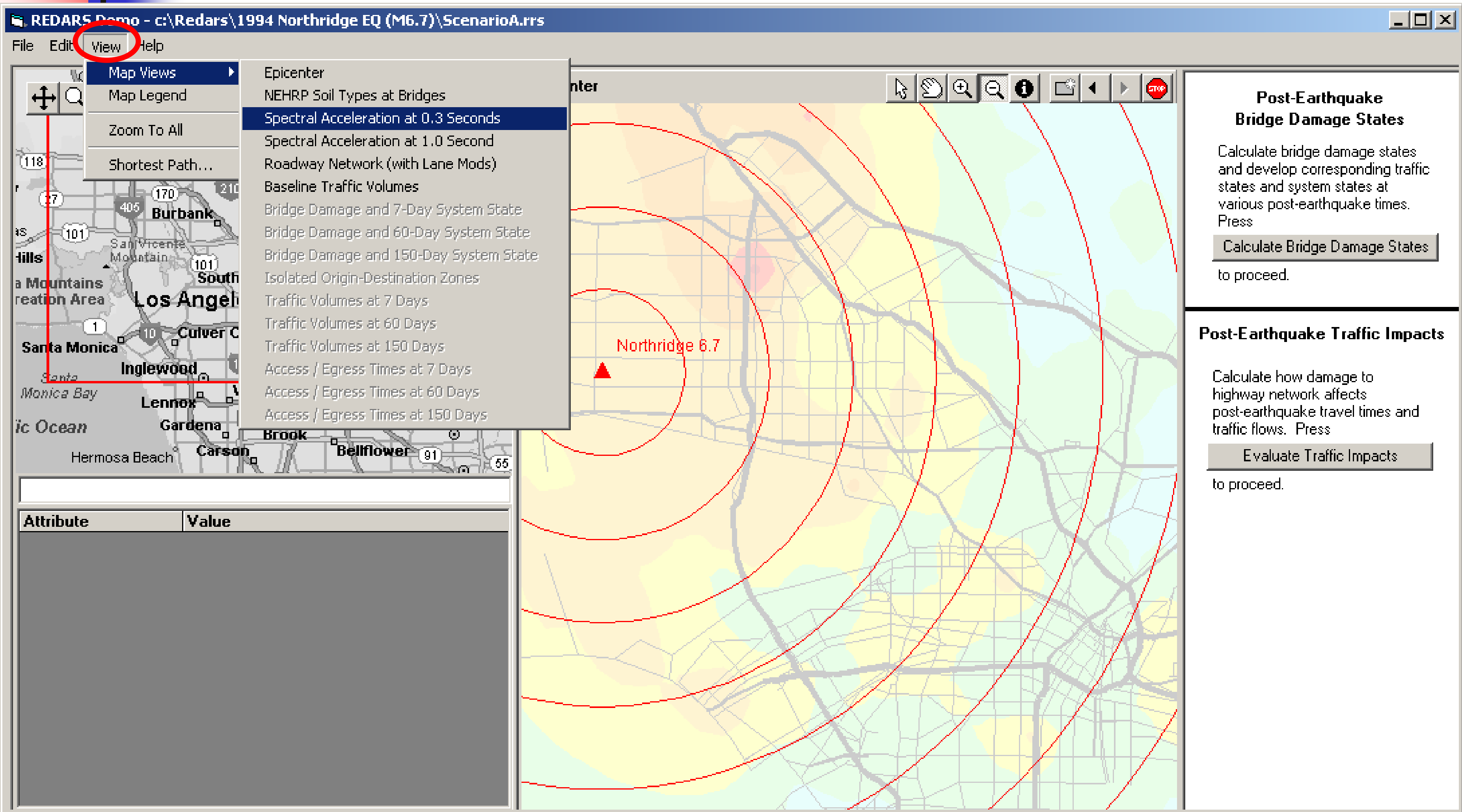
DIALOGUE BOX TO SELECT NORTHRIDGE EQ



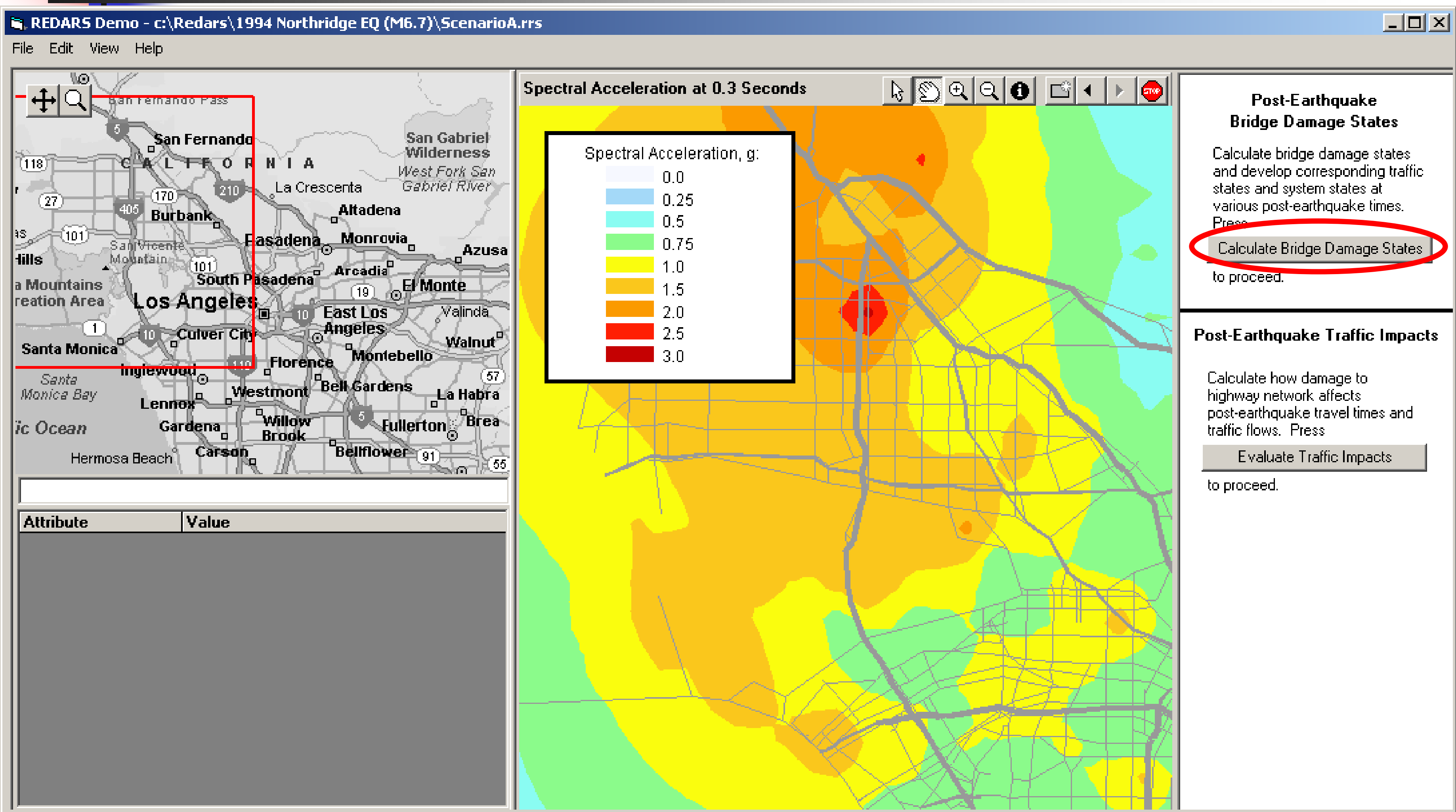
NORTHRIDGE EQ: EPICENTER (SIGNATURE) VIEW



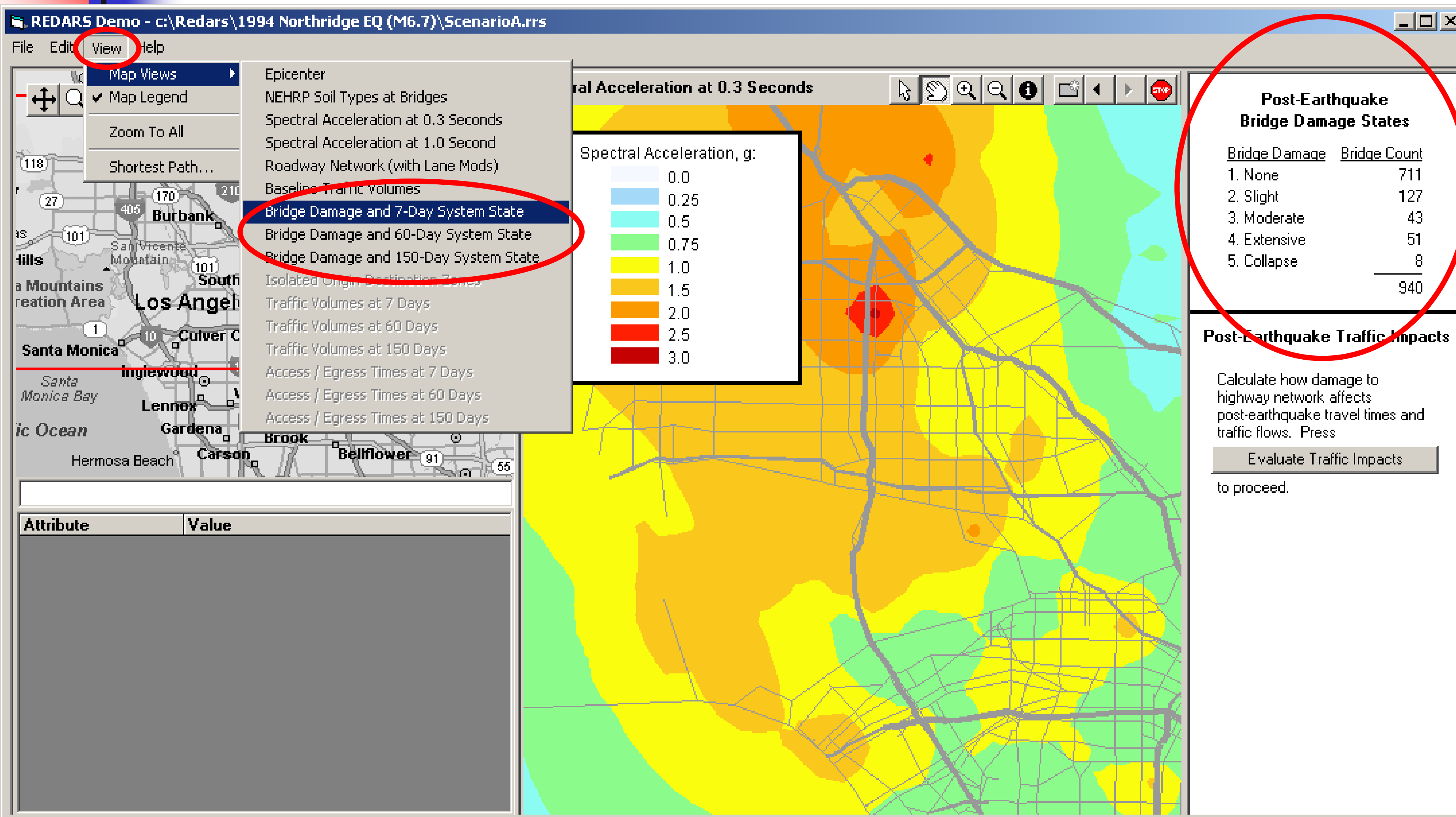
DROP-DOWN MENU:
ACCESS OF GROUND MOTION DATA



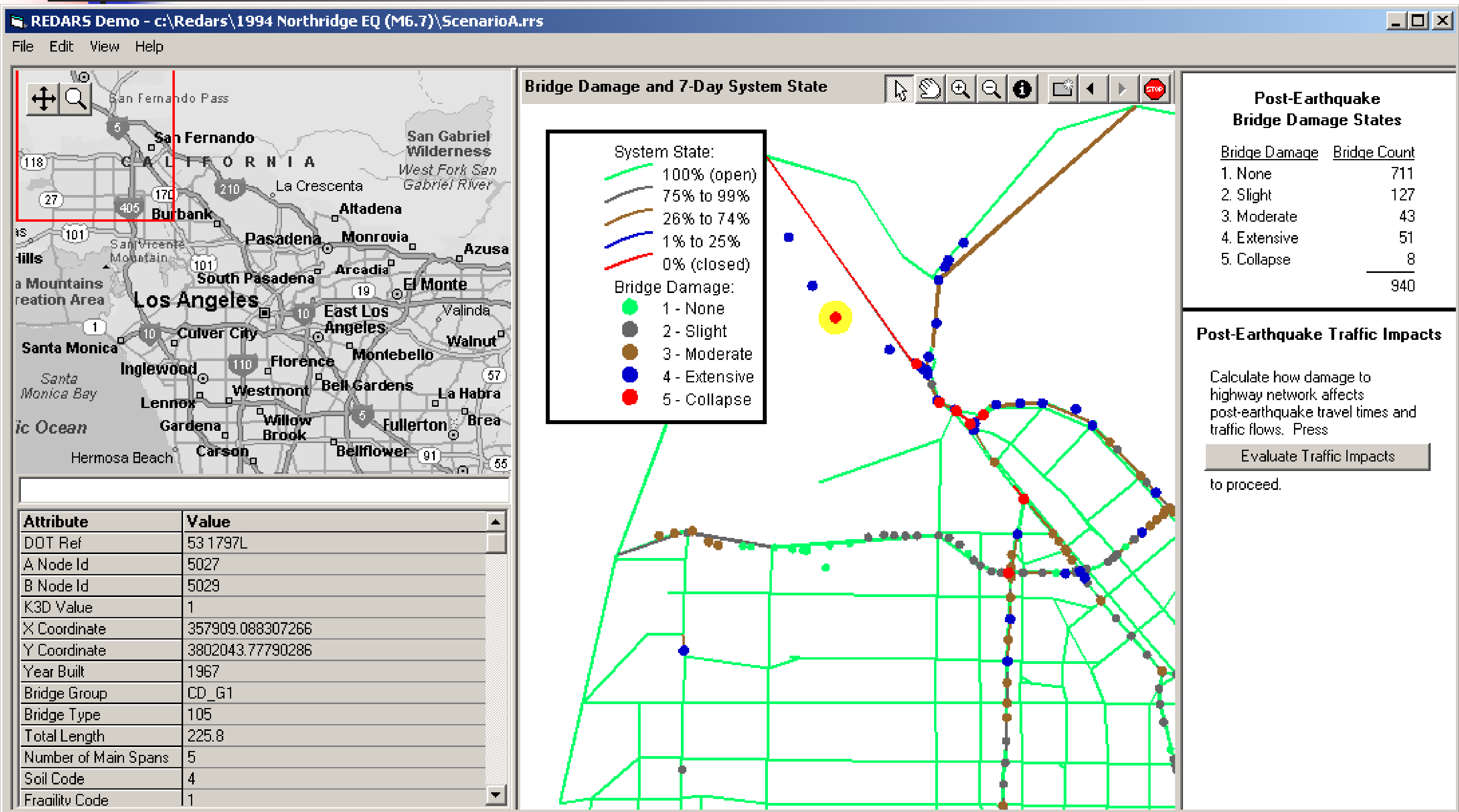
DISPLAY OF GROUND MOTIONS: SPECTRAL ACCELERATIONS AT T = 0.3 SEC.



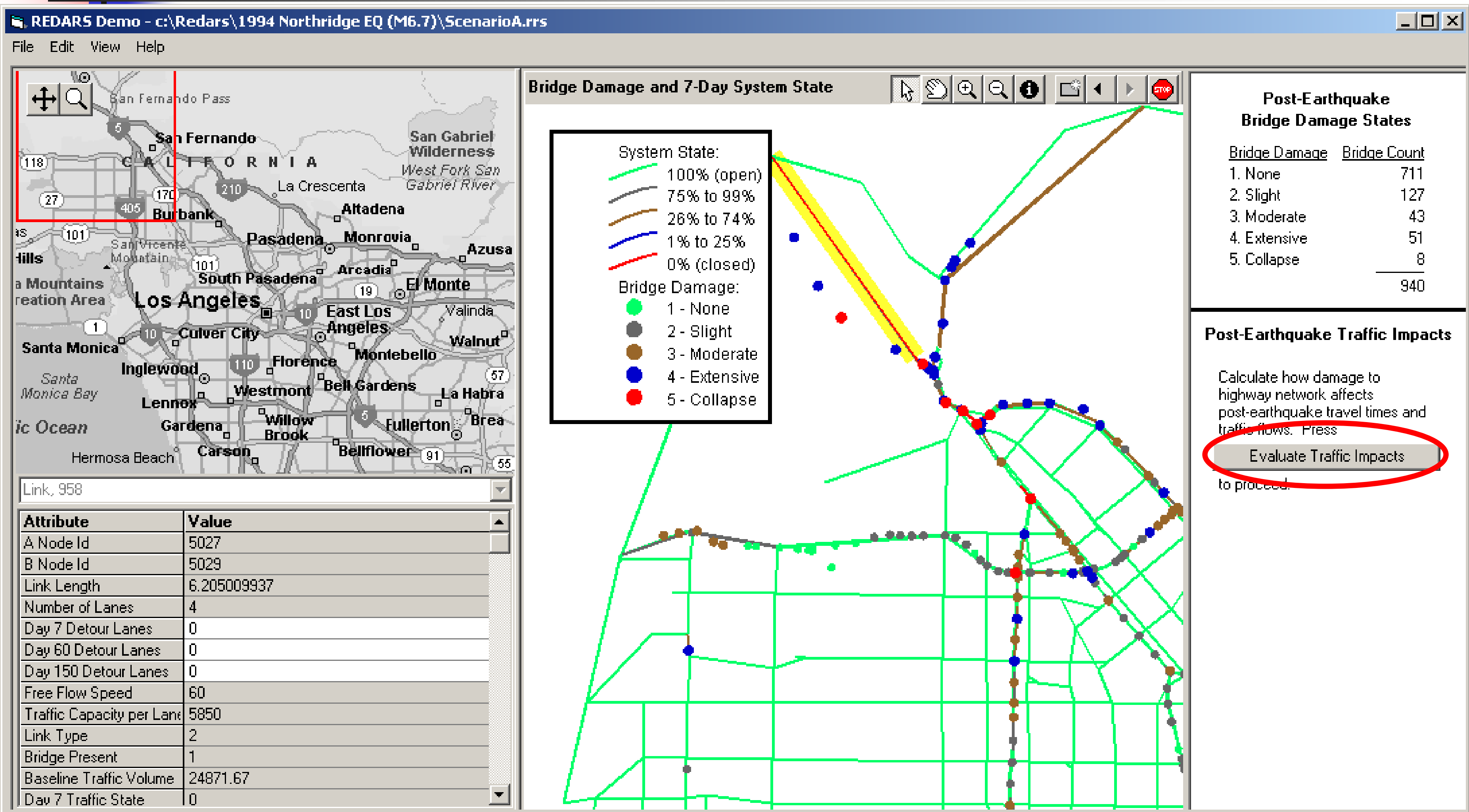
DROP-DOWN MENU: ACCESS BRIDGE DAMAGE & SYSTEM STATE DISPLAYS



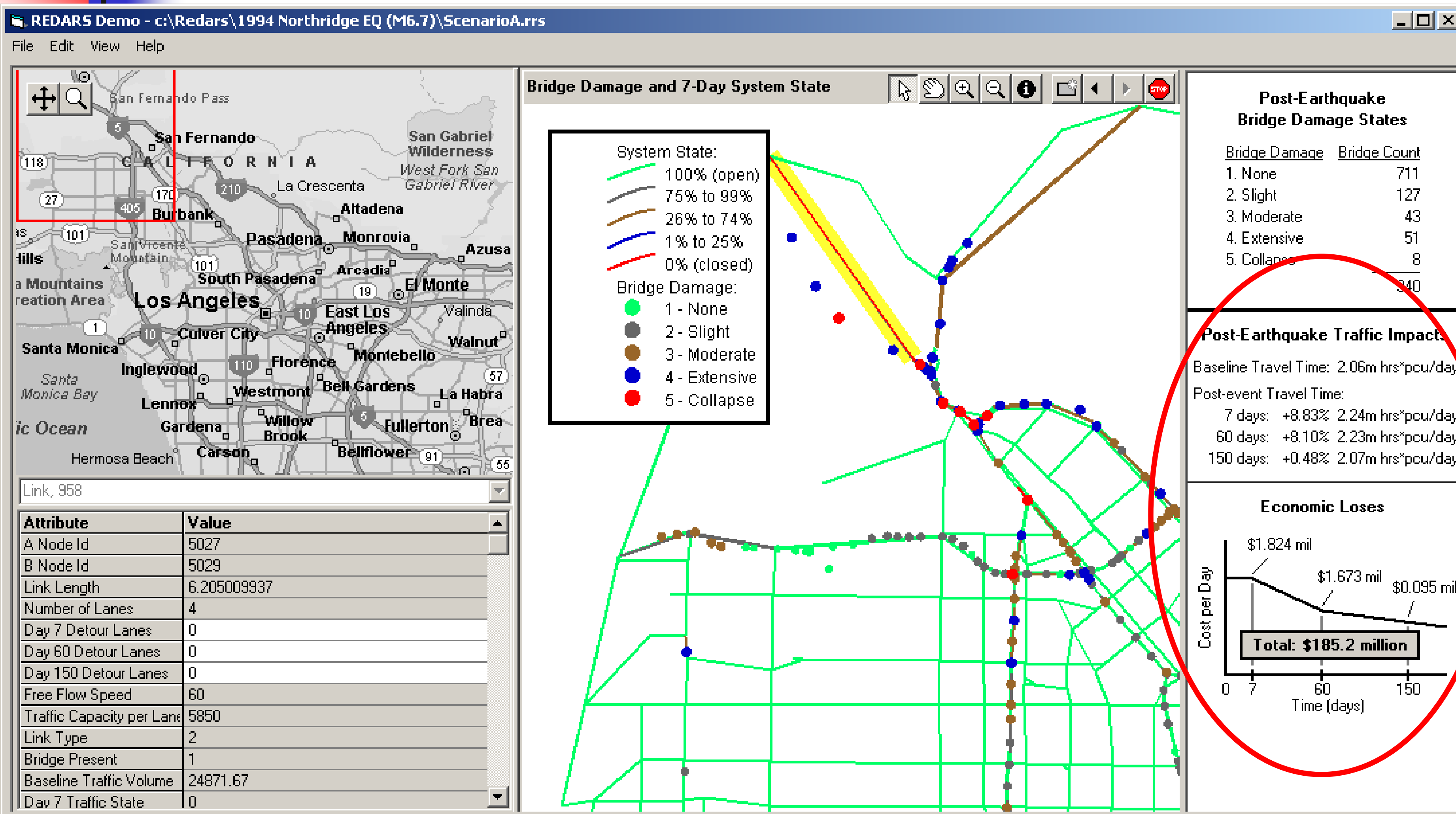
BRIDGE DAMAGE & SYSTEM STATES 7-DAYS AFTER EQ: (INDIVIDUAL BRIDGE DATA DISPLAY)



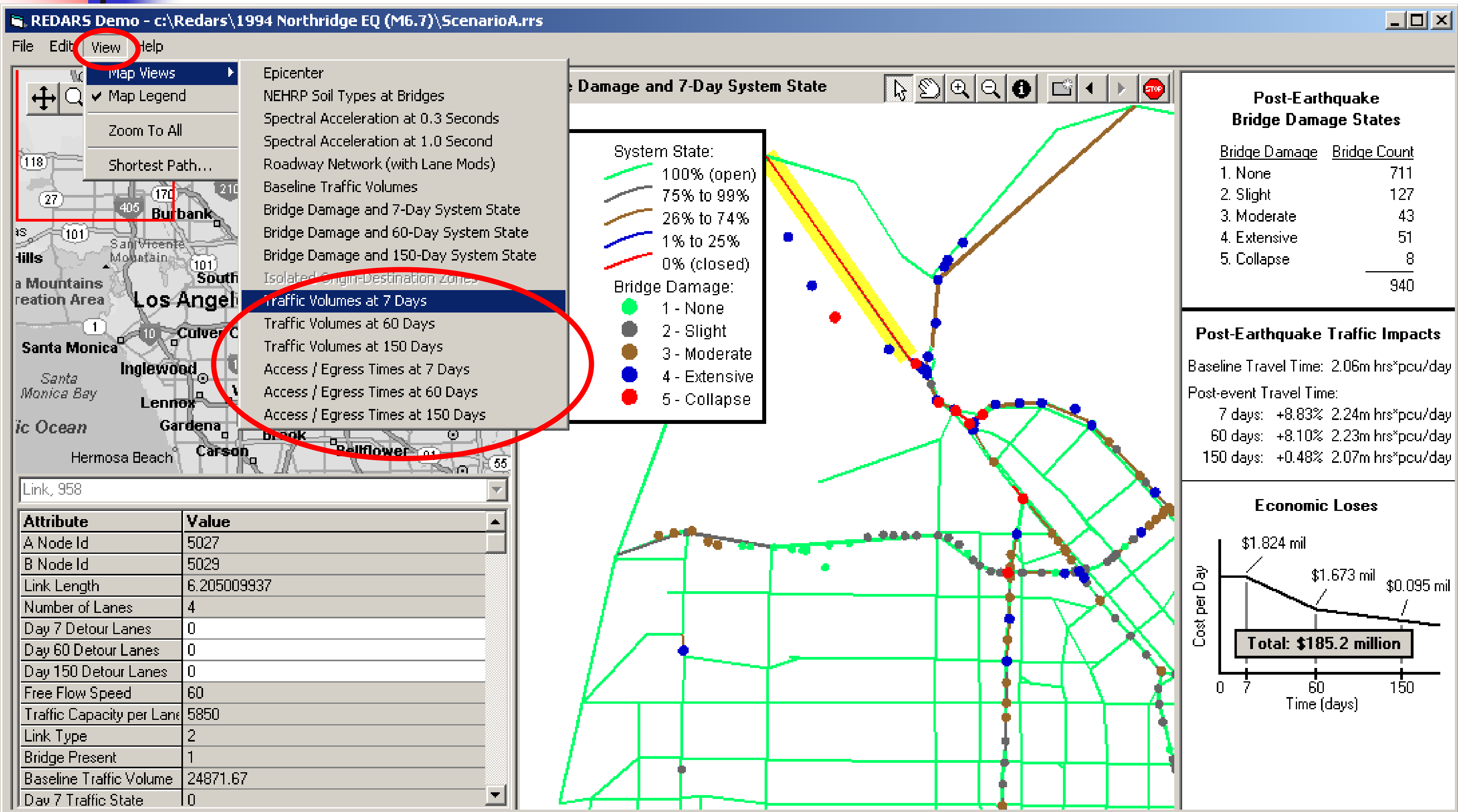
BRIDGE DAMAGE & SYSTEM STATES 7-DAYS AFTER EQ: (INDIVIDUAL LINK DATA DISPLAY)



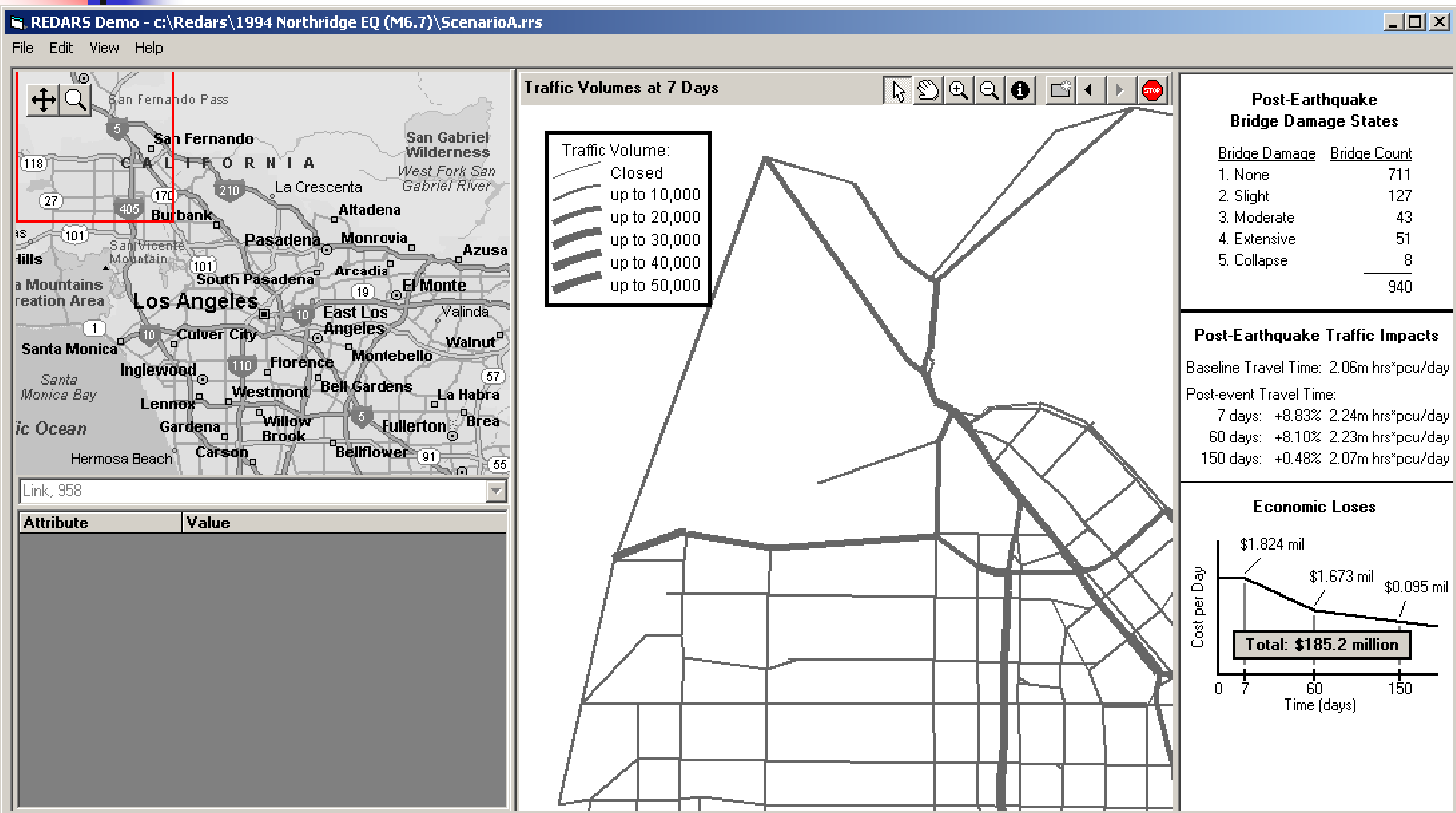
AFTER NETWORK ANALYSIS: TRAVEL TIME & ECONOMIC LOSS DISPLAY



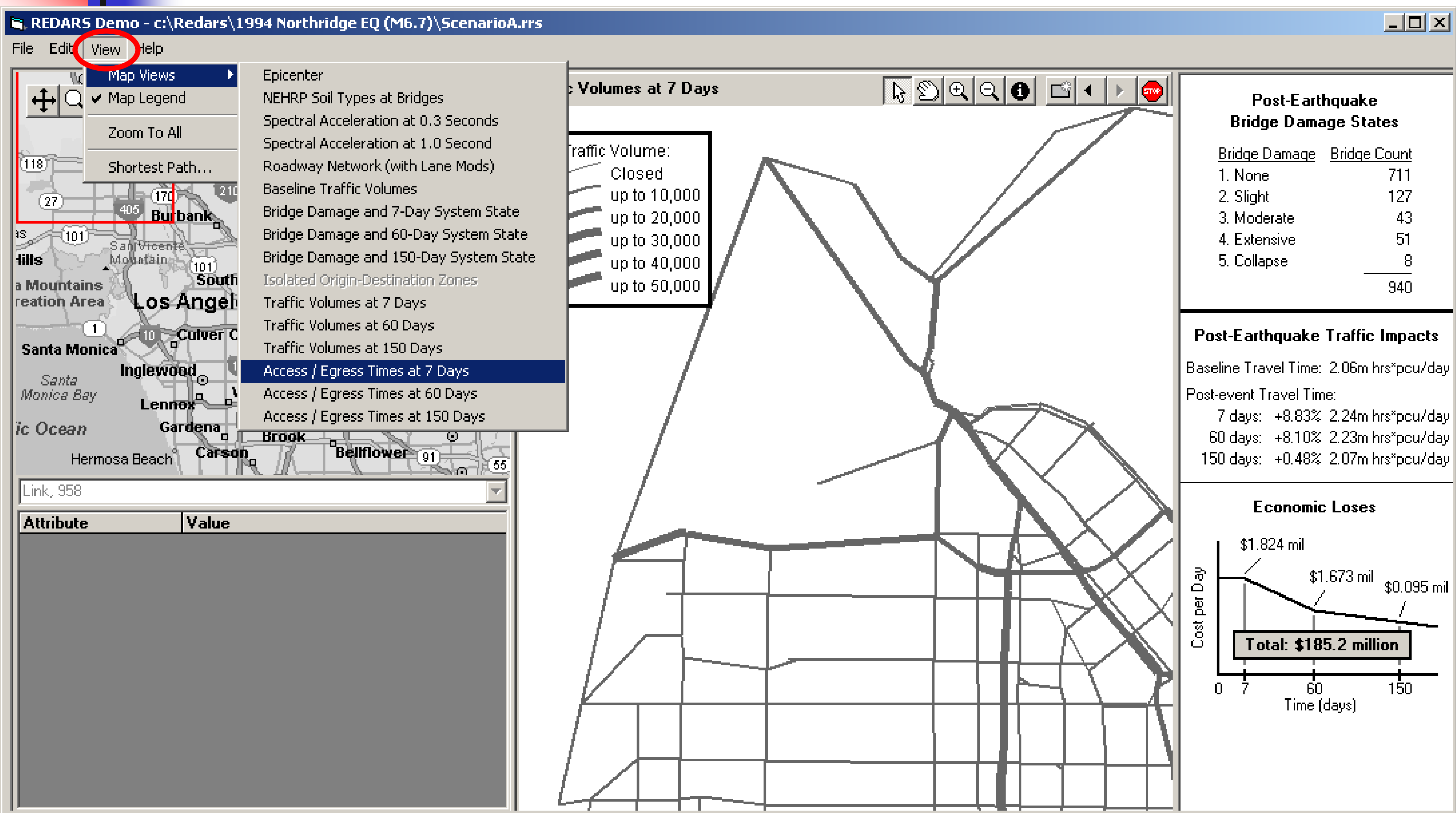
DROP-DOWN MENU: ACCESS DISPLAY OF TRAFFIC VOLUMES 7-DAYS AFTER EQ



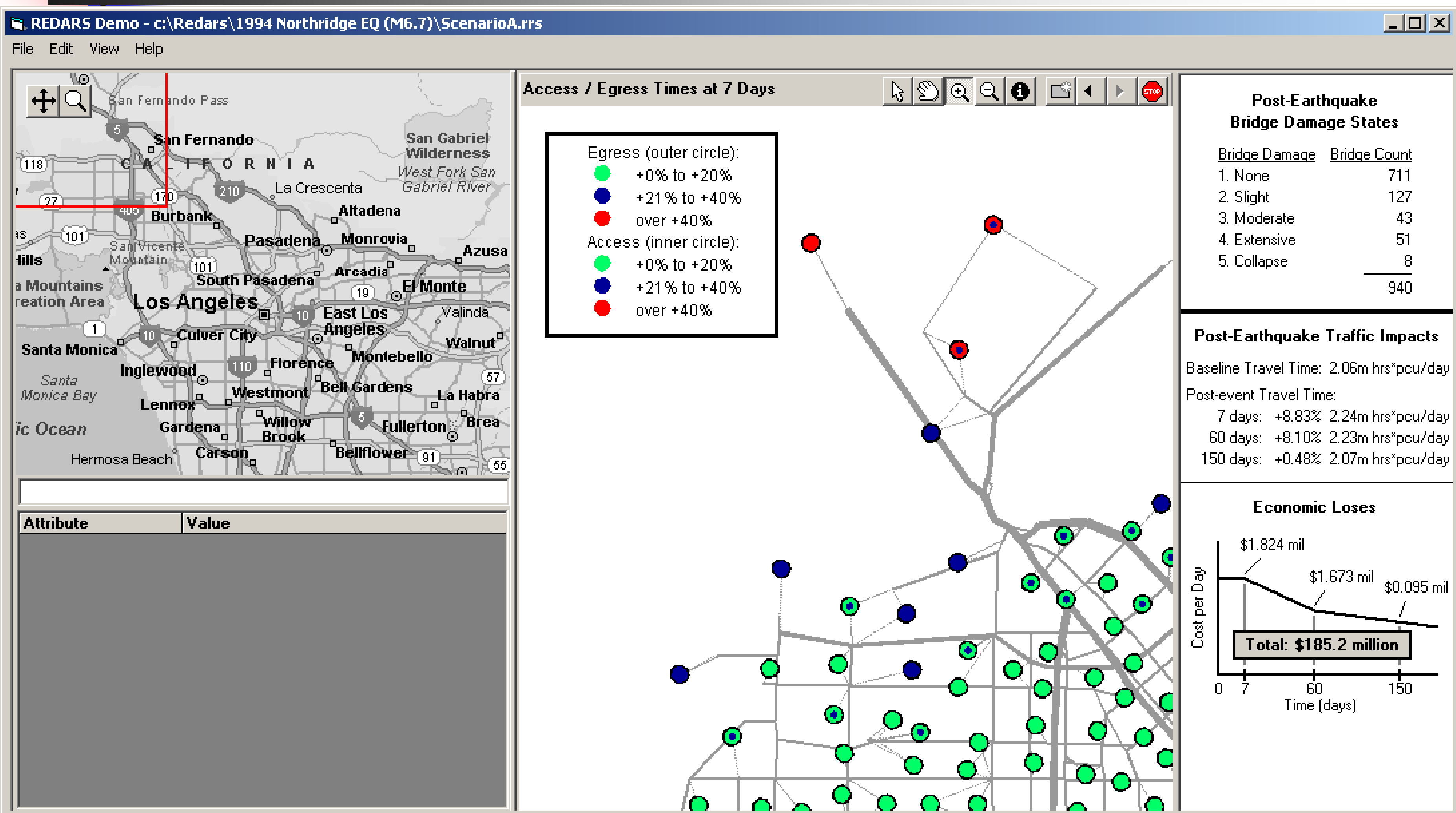
DISPLAY OF TRAFFIC VOLUMES 7-DAYS AFTER EQ



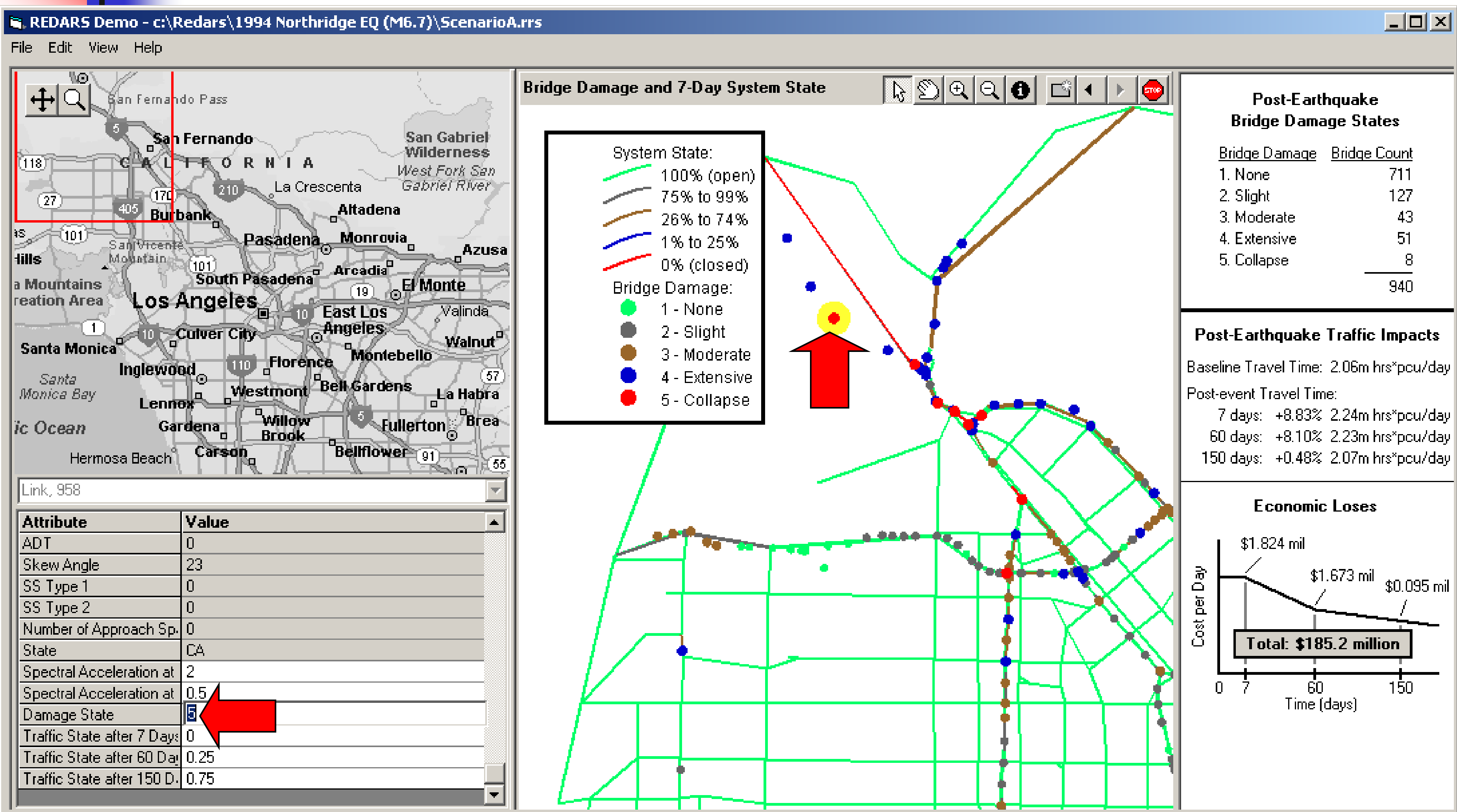
DROP-DOWN MENU: ACCESS DISPLAY ACCESS-EGRESS TIMES 7-DAYS AFTER EQ



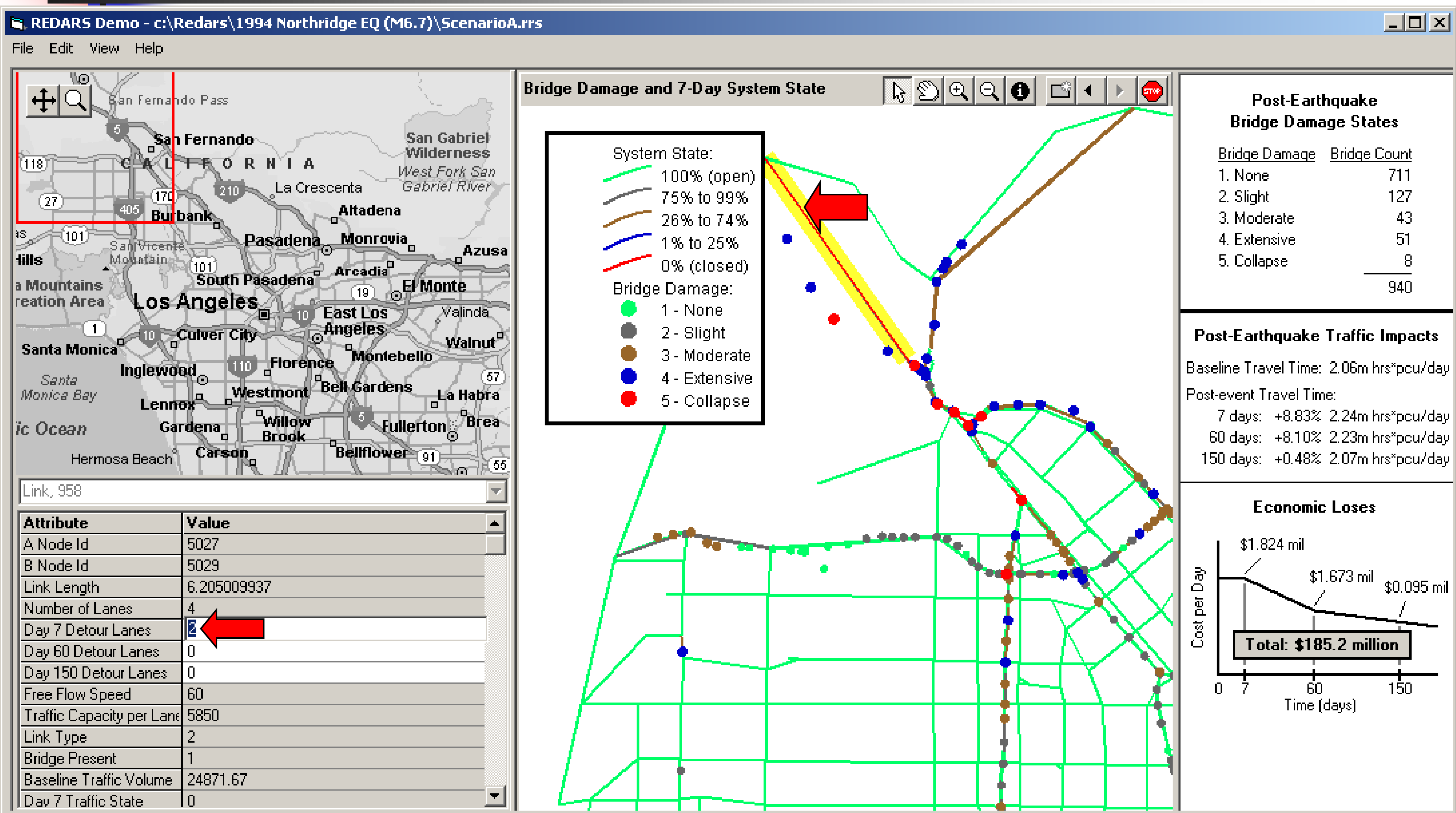
DISPLAY OF EQ EFFECTS ON ACCESS-EGRESS TIMES 7-DAYS AFTER EQ



UPDATING OF BRIDGE DAMAGE DATA IN REAL-TIME AFTER EQ



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



Multi-hazard Bridge Design Criteria

AASHTO Hazard Loadings

- Lack of consistency in different hazard loading requirements
  - Earthquake: 1000 year Return Period (from AASHTO 07)
    - 2500 year (NEHRP)
  - Wind: 50 year Return Period (from ACSE-7-95)
  - Scour 100 year Return Period (from HEC-18)
  - Live Load: 75 year Return Period (from HL-93)
  - Collision Annual failure rate
- Lack of consideration for the possible simultaneous occurrence of two or more events

SAFETEA-LU Seismic & Multi-hazards Research - 2005-2009

- For MCEER (Buffalo)- $4.0 M Advancing Seismic Design and Construction Technology for Highway System
- For UNR (RENO) – $4.0 M Developing Integrated System for Seismic Risk Assessment
- For MCEER (Buffalo) – $3.0M Developing Multiple Hazard Design Principle for Highway Bridges

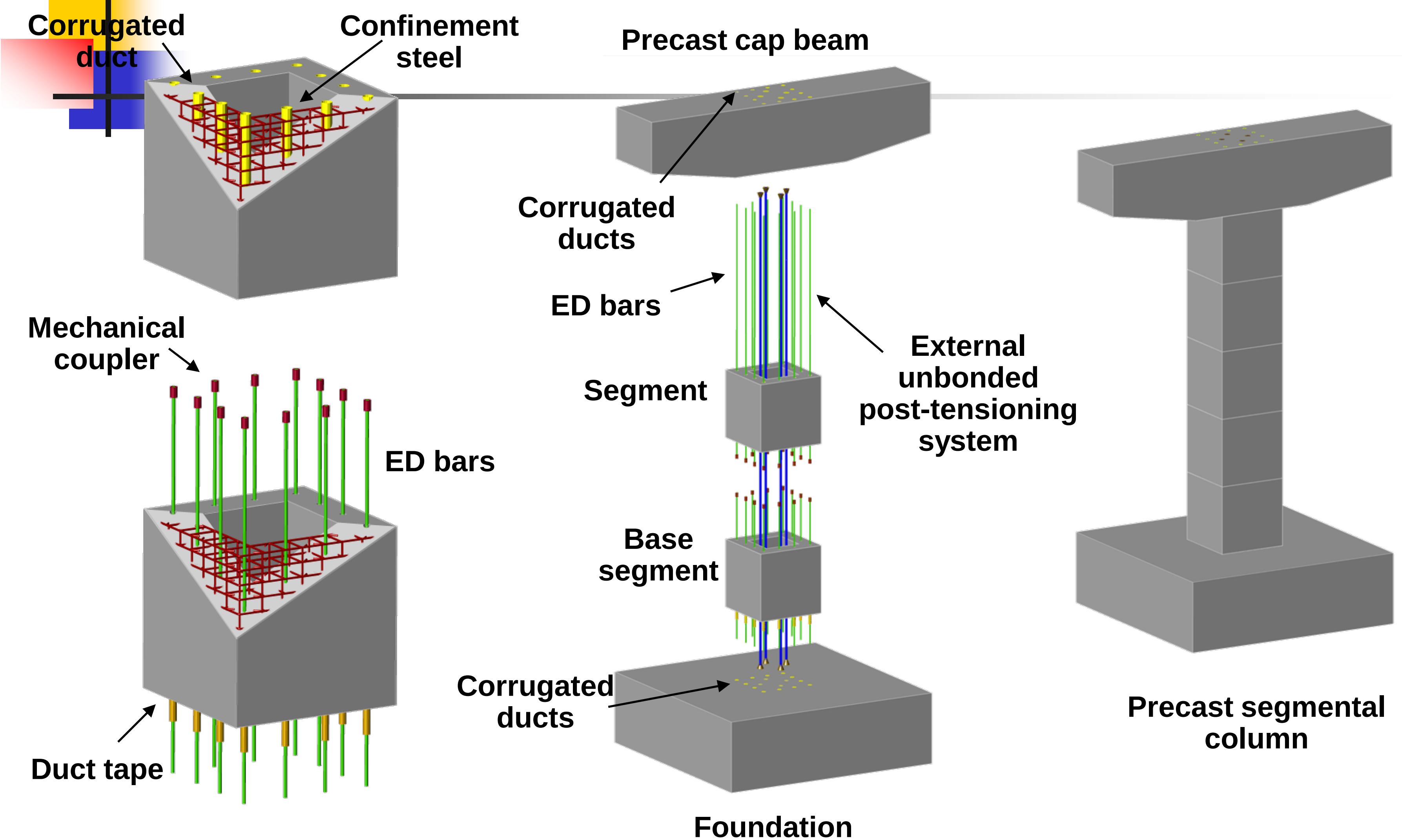
SAFETEA-LU

- For MCEER - about 4.0M Advancing Seismic Design and Construction Technology for Highway System
  - Developing Accelerated Bridge Construction Detail in High Seismicity Area
  - Innovative Bridge Technology in Advancing Seismic Response (Roller Bearing and others.)
  - Opportunity Researches
  - Technology Transfer/ Exchange : National Seismic Conferences & Others workshops..

Seismic Research (Title V)

- For MCEER - about $4.0M Advancing Seismic Design and Construction Technology for Highway System - Major Deliverables
  - Recommended Design Guidelines with Design Examples for Prefabricated and Segmentally Constructed Bridges in Seismicity Area
  - Innovative Bridge Technology in Advancing Seismic Response (Roller Bearing and others.) of Precast Reinforced Concrete Bridges using Accelerated Bridge Construction Technology.
  - Advancing Geo-technical Technology in Seismic Design and Modeling (SFSI)

Proposed Column with ED Bars



SAFETEA-LU

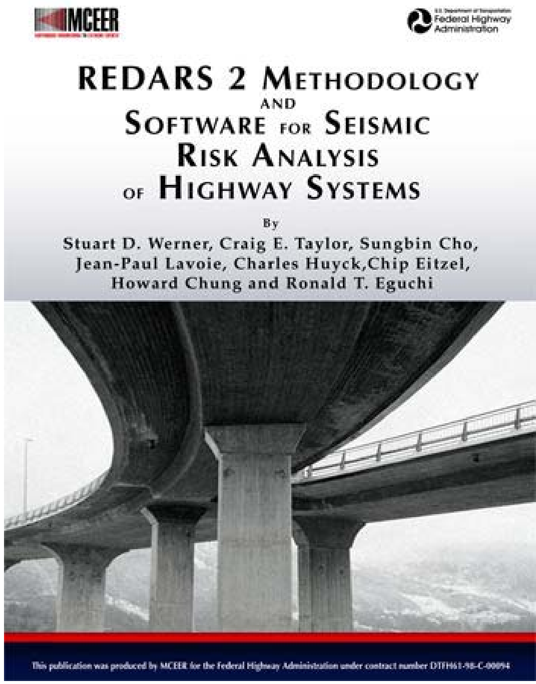
- For UNR (RENO) - about $4.0M   Developing Integrated System for Seismic Risk Assessment

  - - **ENHANCEMENTS TO LOSS-ESTIMATION TECHNOLOGIES FOR HIGHWAY SYSTEMS**
    - REDARS-2™ CUSTOMIZATION FOR RESILIENCE STUDIES
    - CHARACTERIZATIONS OF SEISMIC HAZARDS FOR NEAR-FAULT BRIDGES
  - - **DESIGN GUIDELINES AND FRAGILITY FUNCTIONS**
    - SEISMIC RESPONSE OF HORIZONTALLY-CURVED HIGHWAY BRIDGES
    - NEAR-FAULT BRIDGES STUDY
    - FRAGILITY FUNCTIONS FOR CURVED, NEAR-FAULT, AND OTHER BRIDGES
  - **OPPORTUNITY RESEARCH**

Seismic Research (Title V)

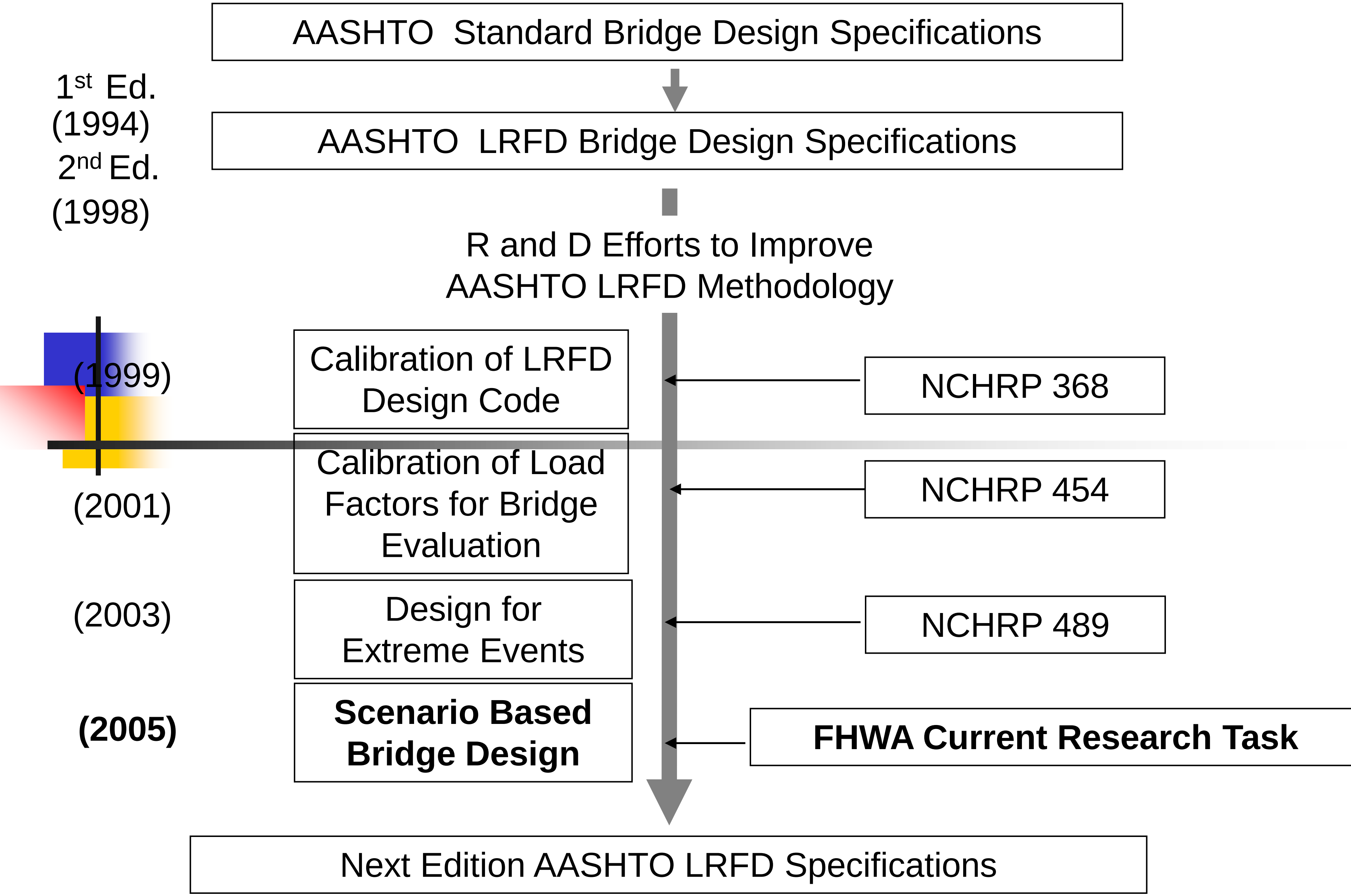
- For UNR (RENO) - about $4.0M Developing Integrated System for Seismic Risk Assessment – Major Deliverables

  - A tool (A new version of REDARS) for the quantification of highway resilience by improving current loss estimation technologies such as REDARS.
  - Factors that affect system resilience, such as damage-tolerant bridge structures and network redundancy.
  - Seismic design guides for curved bridges and bridges in near-fault regions.
  - New technologies for improving the seismic performance of bridges.



Multi-hazard Research (Title I)

- For MCEER (Buffalo) – about $3.0M Developing Multiple Hazard Design Principle for Highway Bridges – Major Deliverables
  - Recommended Design Principles and Methodologies used for all Natural Hazards and Extreme Load Effects
  - Case Evaluation and Studies of Highway Bridge Design Against Multiple-Hazards .
  - Recommended Guide Specification for Isolators & Dampers


AASHTO Standard Bridge Design Specifications
1st Ed. (1994)
2nd Ed. (1998)
AASHTO LRFD Bridge Design Specifications
R and D Efforts to Improve
AASHTO LRFD Methodology
(1999)
Calibration of LRFD Design Code
NCHRP 368
(2001)
Calibration of Load Factors for Bridge Evaluation
NCHRP 454
(2003)
Design for Extreme Events
NCHRP 489
(2005)
Scenario Based Bridge Design
FHWA Current Research Task
Next Edition AASHTO LRFD Specifications

Basic Parameter in Probability Based Approach
The Uniform Reliability Index

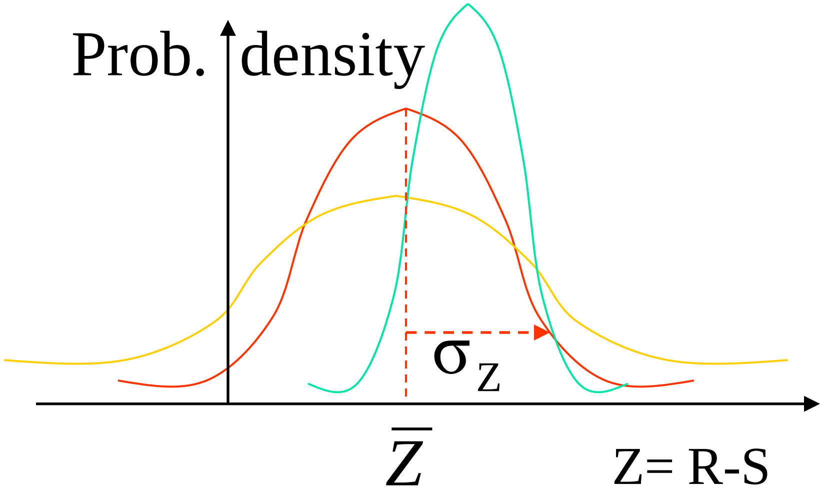
- Margin of safety

$$Z = R - S$$

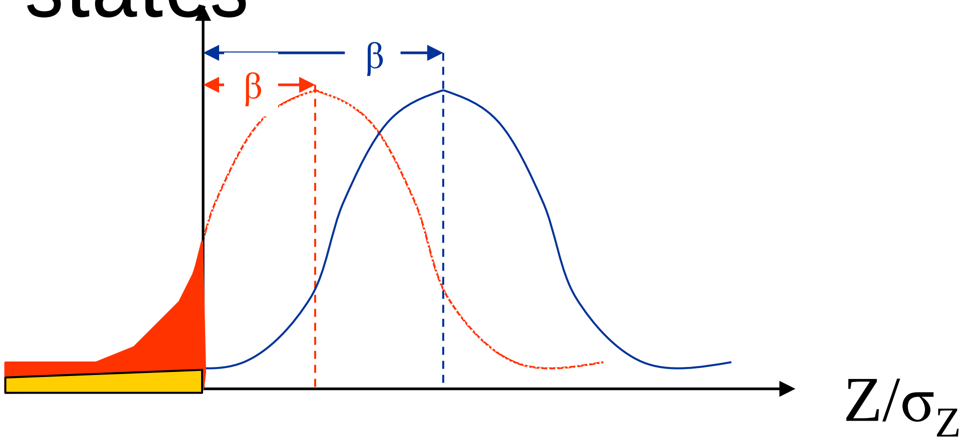
where R is the resistance and S is the loading

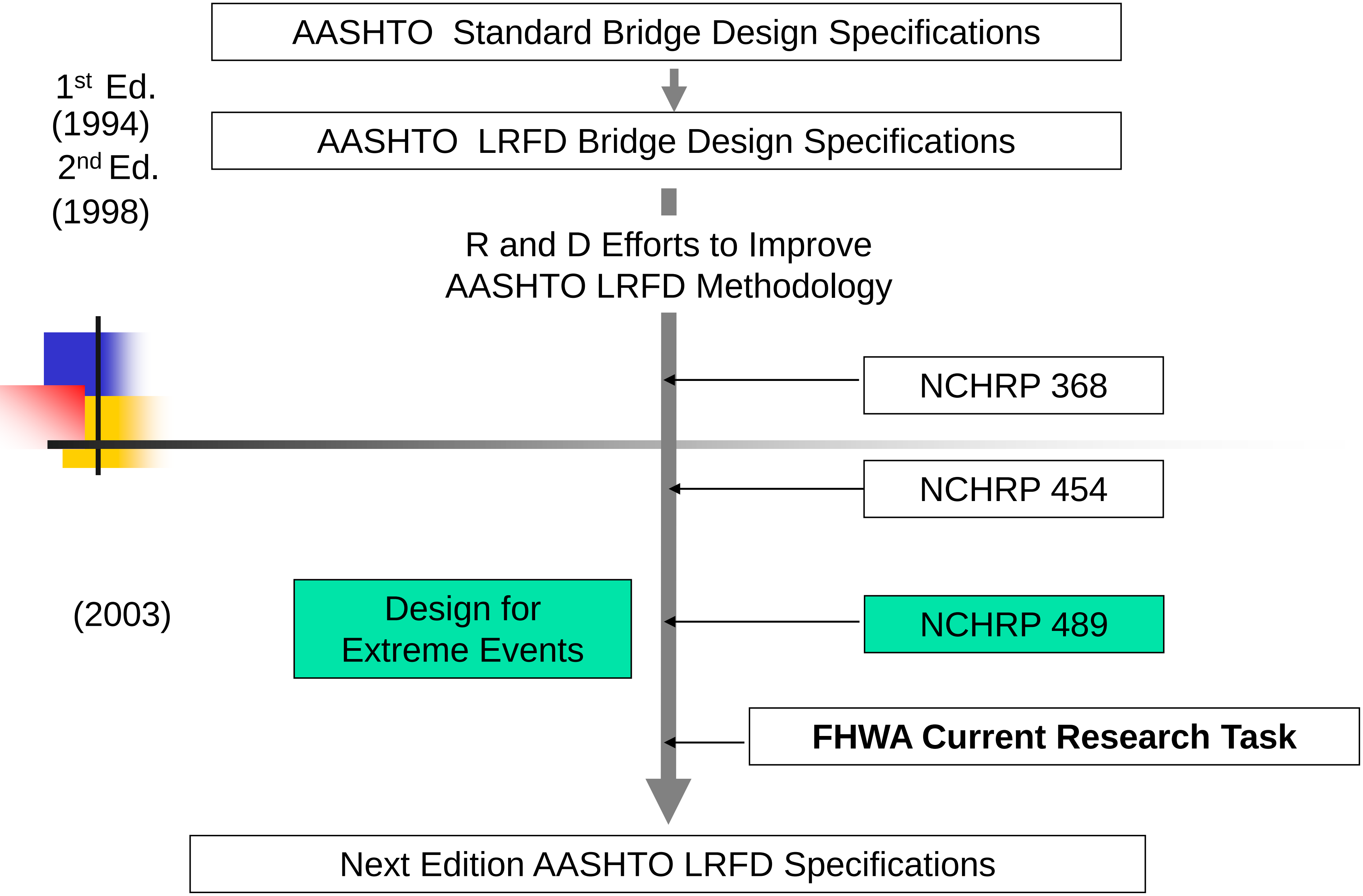
- Reliability Index

$$\beta = \frac{\bar{Z}}{\sigma_Z} = -\frac{\mu_R - \mu_s}{\sqrt{\sigma_R^2 + \sigma_s^2}}$$



- β - Normalized probability measurement of reliability β for design limit states

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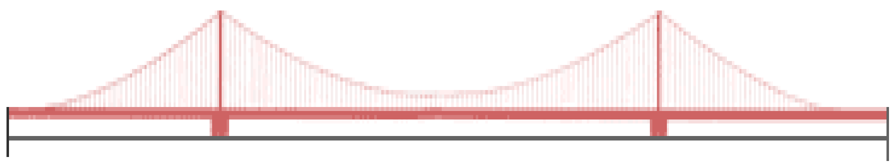
Extreme Scenario Based Multi-Hazard Resilient Bridges

Hazards (Natural hazards, Technical hazards, Terrorist Attacks)



During the hazard event:

- Warning
- Incident response
- Preparedness
- Monitoring

- Limited Damage Incident
- Disaster
- Catastrophe

Summary

- Hazard Impacts to the Bridge Asset Managements
- Integrated “Risk Management” to mitigate natural and man-made hazards
- Needs to develop scenario-based multi-hazard design Criteria (Same principle)
- International collaboration (bridge damage information due to extreme events) is most welcome

Thank you