

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



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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

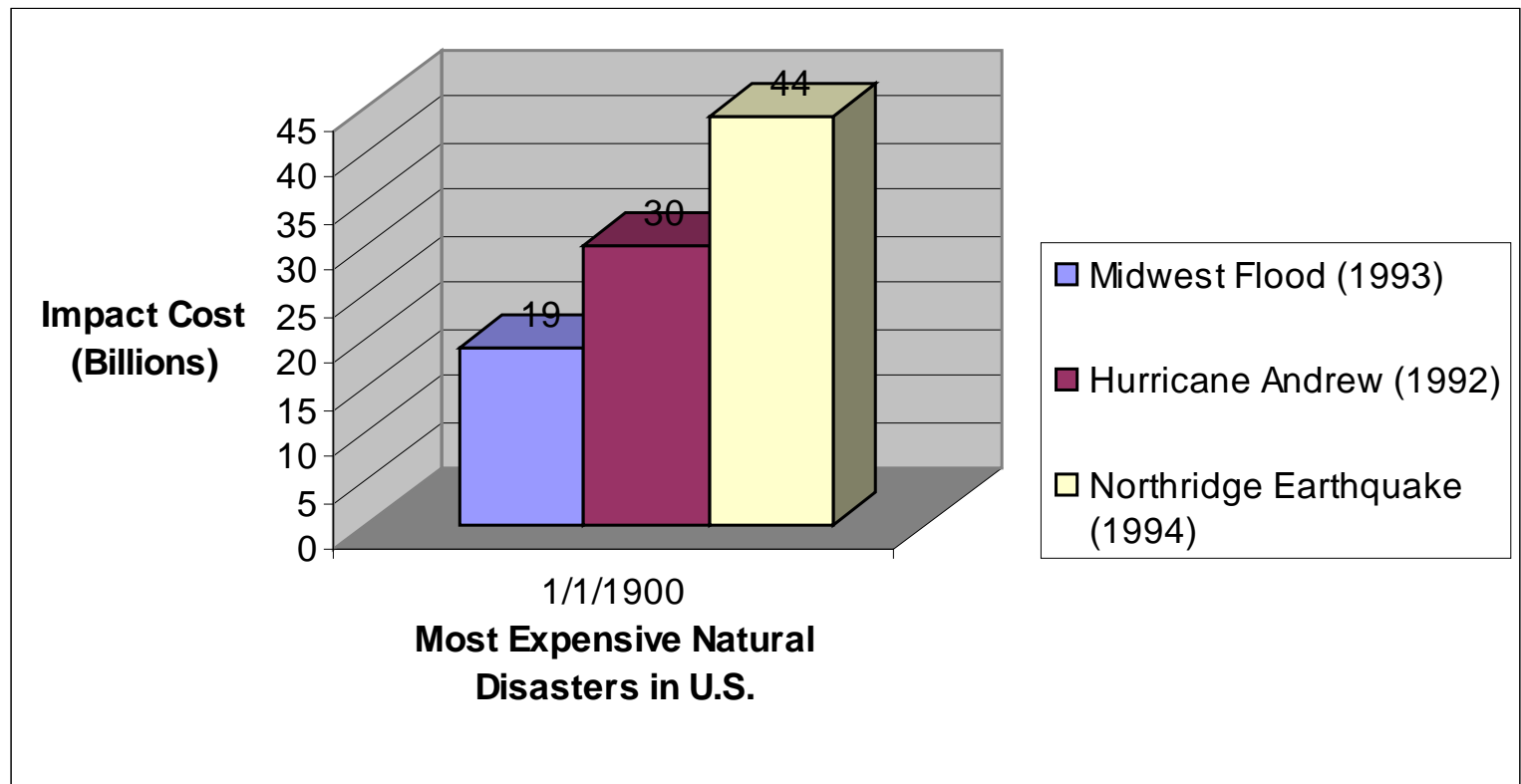


Natural & Man-made Hazards

- 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

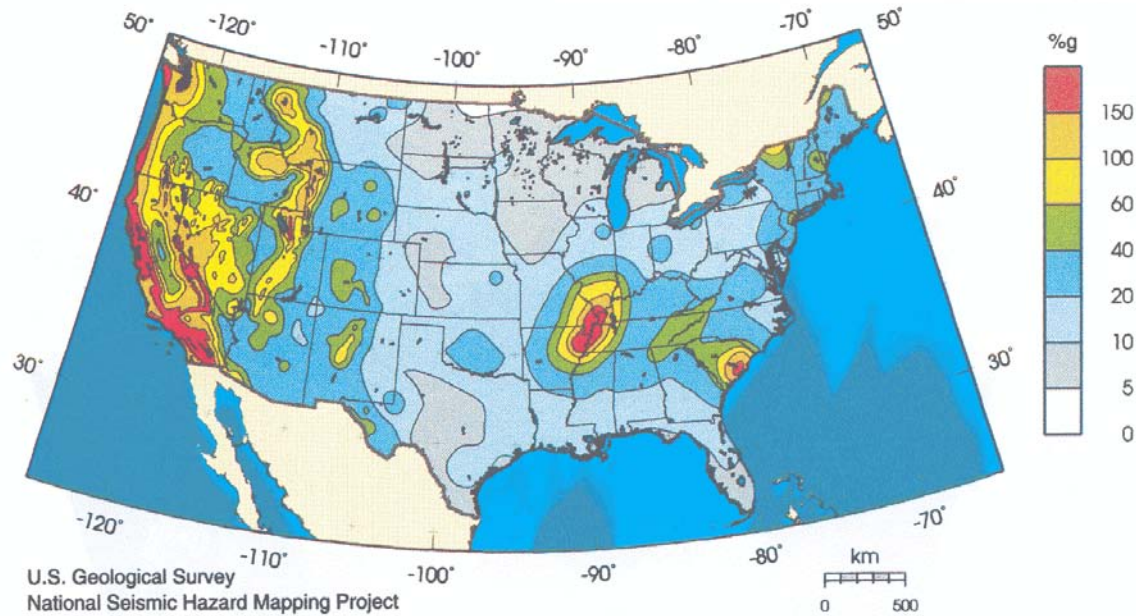


Figure 9a. MCE ground motion map of the 48 conterminous states for the 0.2 sec horizontal spectral response acceleration (%g), 5% of critical damping, Site Class B.

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
Federal Highway Administration

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

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

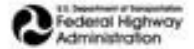
Location	Date	Magnitude	Damages (in Millions)	Deaths
Prince William Sound, AK	03/27/1964	8.4	\$311.0	125
San Fernando, CA	02/09/1971	6.6	\$505.0	65
Loma Prieta, CA	10/17/1989	7.1	\$6,000.0	63
Northridge, CA	01/17/1994	6.7	\$20,000.0	61
Nisqually, WA	02/28/2001	6.8	\$2,100.0	1

TYPICAL RETROFITS



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

Seismic Isolation of Highway Bridges

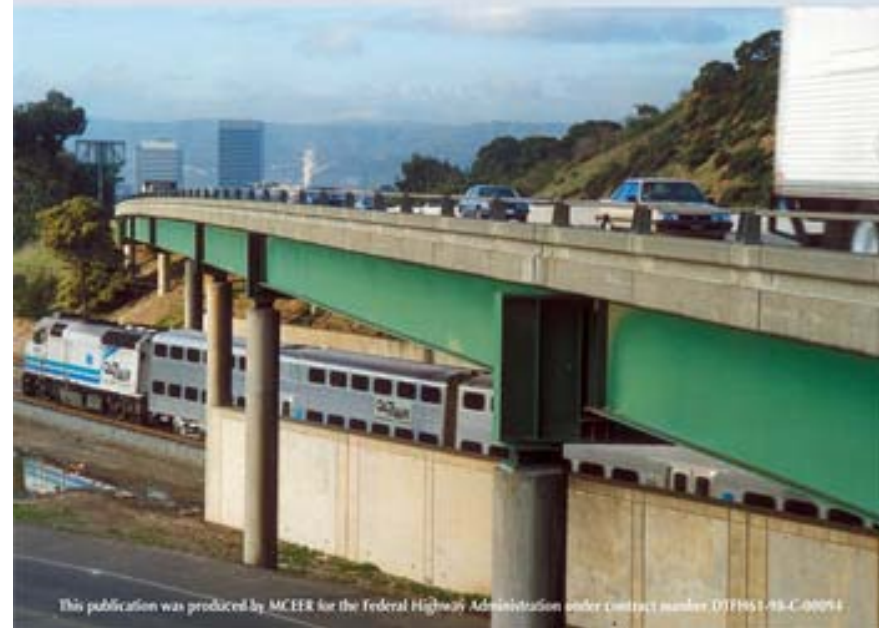


- **I.G. Buckle, M. Constantinou, M. Dicleli and H. Ghasemi**
- *Seismic Isolation of Highway Bridges* presents the principles of isolation for bridges, develops step by step methods of analysis, explains material and design issues for elastomeric and sliding isolators, and gives detailed examples of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

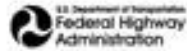
SEISMIC ISOLATION OF HIGHWAY BRIDGES

By

Ian Buckle, Michael Constantinou,
Murat Dicleli and Hamid Ghasemi



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.

SEISMIC RETROFITTING GUIDELINES FOR COMPLEX STEEL TRUSS HIGHWAY BRIDGES

By
Tom Ho, Roupen Donikian, Tim Ingham,
Chuck Seim and Austin Pan



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

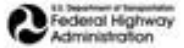
PLANNING PREPAREDNESS



- 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 2 METHODOLOGY AND SOFTWARE FOR SEISMIC RISK ANALYSIS OF HIGHWAY SYSTEMS

By
Stuart D. Werner, Craig E. Taylor, Sungbin Cho,
Jean-Paul Lavoie, Charles Huyck, Chip Eitzel,
Howard Chung and Ronald T. Eguchi





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

The screenshot displays the REDARS 1.0 software interface. The window title is "REDARS Demo". The menu bar includes "File", "Edit", "View", and "Help". The "File" menu is open, showing options: "Open...", "Save", "Save As...", "Print Screen", "Print Map...", "Properties...", and "Exit". The "File" menu item is circled in red. The main map area shows a detailed view of the Los Angeles metropolitan area, including cities like San Fernando, Burbank, Pasadena, Los Angeles, and Fullerton. A toolbar with various navigation and tool icons is located above the map. Below the map is an attribute table with two columns: "Attribute" and "Value".

Attribute	Value
-----------	-------

On the right side of the interface, there are two panels:

- Post-Earthquake Bridge Damage States**
Calculate bridge damage states and develop corresponding traffic states and system states at various post-earthquake times. Press

to proceed.
- Post-Earthquake Traffic Impacts**
Calculate how damage to highway network affects post-earthquake travel times and traffic flows. Press

to proceed.

DIALOGUE BOX TO SELECT NORTHRIDGE EQ

The screenshot displays the REDARS Demo application interface. The main window shows a map of the Los Angeles area with various cities and highways labeled. An 'Open Existing Scenario File' dialog box is open, showing a list of earthquake scenarios. The '1994 Northridge EQ (M6.7)' scenario is selected. The dialog box also shows the 'Look in' path as 'Redars' and the 'Files of type' as 'REDARS Scenario Files (*.rsf)'. On the right side of the application, there are two panels. The top panel is titled 'Post-Earthquake Bridge Damage States' and contains the text: 'Calculate bridge damage states and develop corresponding traffic states and system states at various post-earthquake times. Press Calculate Bridge Damage States to proceed.' The bottom panel is titled 'Post-Earthquake Traffic Impacts' and contains the text: 'Calculate how damage to highway network affects post-earthquake travel times and traffic flows. Press Evaluate Traffic Impacts to proceed.'

REDARS Demo
File Edit View Help

San Fernando Pass
San Fernando
San Gabriel Wilderness
West Fork San Gabriel River
La Crescenta
Altadena
Burbank
Pasadena
Los Angeles
Santa Monica
Inglewood
Gardena
Carson
Hermosa Beach
Santa Monica Bay
Pacific Ocean

Open Existing Scenario File

Look in: Redars

- 1971 San Fernando EQ (M6.7)
- 1987 Whittier Narrows EQ (M5.9)
- 1994 Northridge EQ (M6.7)
- Newport-Inglewood Fault Rupture Scenario (M6.9)
- Raymond Fault Rupture Scenario (M6.5)
- San Andreas 1857 Fault Rupture Scenario (M7.8)
- Santa Monica Fault Rupture Scenario (M6.6)
- Whittier Fault Rupture Scenario (M6.8)

File name: Scenario
Files of type: REDARS Scenario Files (*.rsf)

Open Cancel

Post-Earthquake Bridge Damage States

Calculate bridge damage states and develop corresponding traffic states and system states at various post-earthquake times. Press

Calculate Bridge Damage States to proceed.

Post-Earthquake Traffic Impacts

Calculate how damage to highway network affects post-earthquake travel times and traffic flows. Press

Evaluate Traffic Impacts to proceed.

NORTHRIDGE EQ: EPICENTER (SIGNATURE) VIEW

REDARS Demo - c:\Redars\1994 Northridge EQ (M6.7)\ScenarioA.rrs

File Edit View Help

Post-Earthquake Bridge Damage States

Calculate bridge damage states and develop corresponding traffic states and system states at various post-earthquake times. Press

to proceed.

Post-Earthquake Traffic Impacts

Calculate how damage to highway network affects post-earthquake travel times and traffic flows. Press

to proceed.

Attribute	Value
-----------	-------

DROP-DOWN MENU: ACCESS OF GROUND MOTION DATA

REDARS Demo - c:\Redars\1994 Northridge EQ (M6.7)\ScenarioA.rrs

File Edit **View** Help

- Map Views
- Map Legend
- Zoom To All
- Shortest Path...

- Epicenter
- NEHRP Soil Types at Bridges
- Spectral Acceleration at 0.3 Seconds**
- Spectral Acceleration at 1.0 Second
- Roadway Network (with Lane Mods)
- Baseline Traffic Volumes
- Bridge Damage and 7-Day System State
- Bridge Damage and 60-Day System State
- Bridge Damage and 150-Day System State
- Isolated Origin-Destination Zones
- Traffic Volumes at 7 Days
- Traffic Volumes at 60 Days
- Traffic Volumes at 150 Days
- Access / Egress Times at 7 Days
- Access / Egress Times at 60 Days
- Access / Egress Times at 150 Days

Northridge 6.7

Post-Earthquake Bridge Damage States

Calculate bridge damage states and develop corresponding traffic states and system states at various post-earthquake times. Press

to proceed.

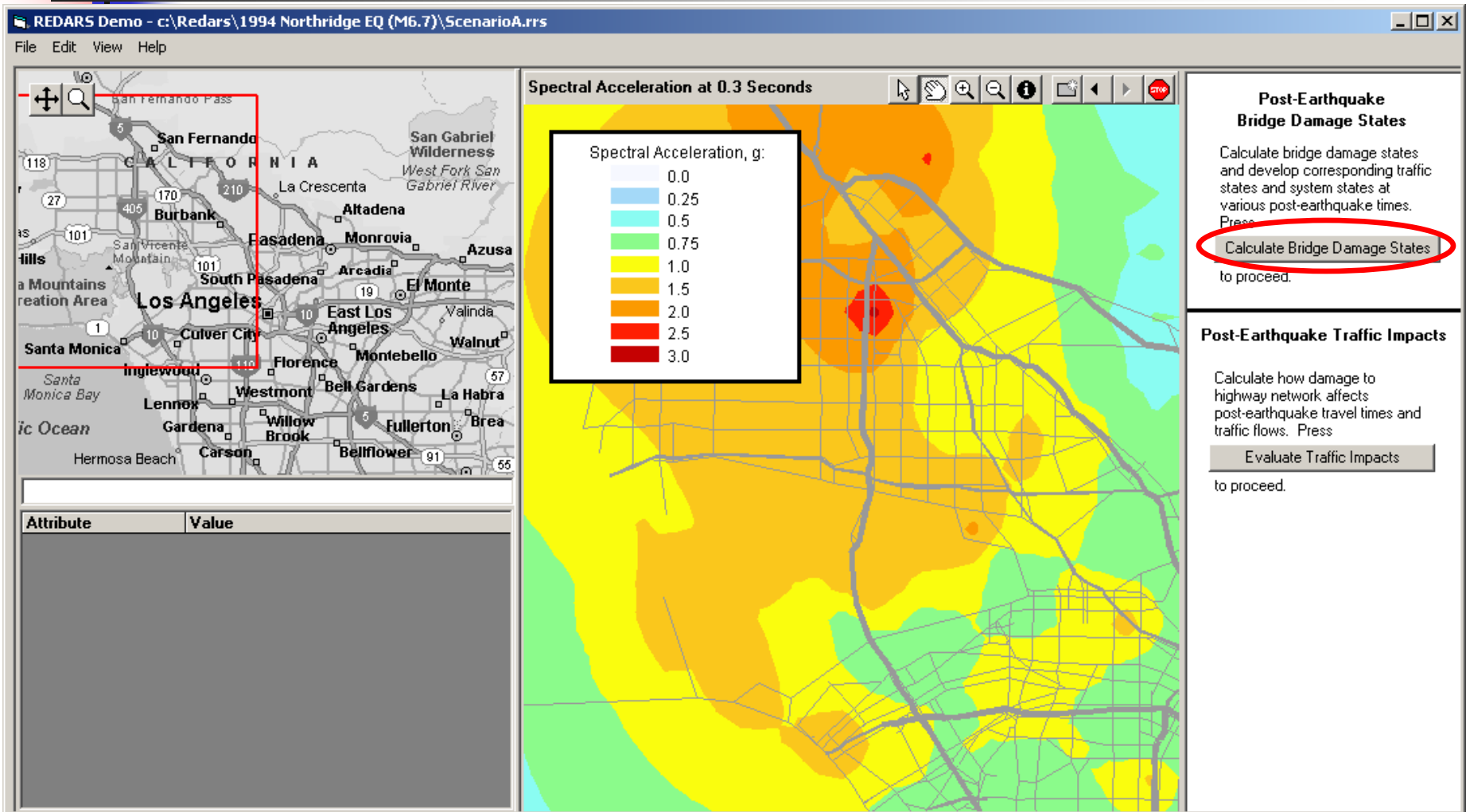
Post-Earthquake Traffic Impacts

Calculate how damage to highway network affects post-earthquake travel times and traffic flows. Press

to proceed.

Attribute	Value
-----------	-------

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



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

REDARS Demo - c:\Redars\1994 Northridge EQ (M6.7)\ScenarioA.rrs

File Edit **View** Help

- Map Views
- Map Legend
- Zoom To All
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- Traffic Volumes at 150 Days
- Access / Egress Times at 7 Days
- Access / Egress Times at 60 Days
- Access / Egress Times at 150 Days

Spectral Acceleration at 0.3 Seconds

Spectral Acceleration, g:

- 0.0
- 0.25
- 0.5
- 0.75
- 1.0
- 1.5
- 2.0
- 2.5
- 3.0

Post-Earthquake Bridge Damage States

Bridge Damage	Bridge Count
1. None	711
2. Slight	127
3. Moderate	43
4. Extensive	51
5. Collapse	8
	<hr/>
	940

Post-Earthquake Traffic Impacts

Calculate how damage to highway network affects post-earthquake travel times and traffic flows. Press

Evaluate Traffic Impacts

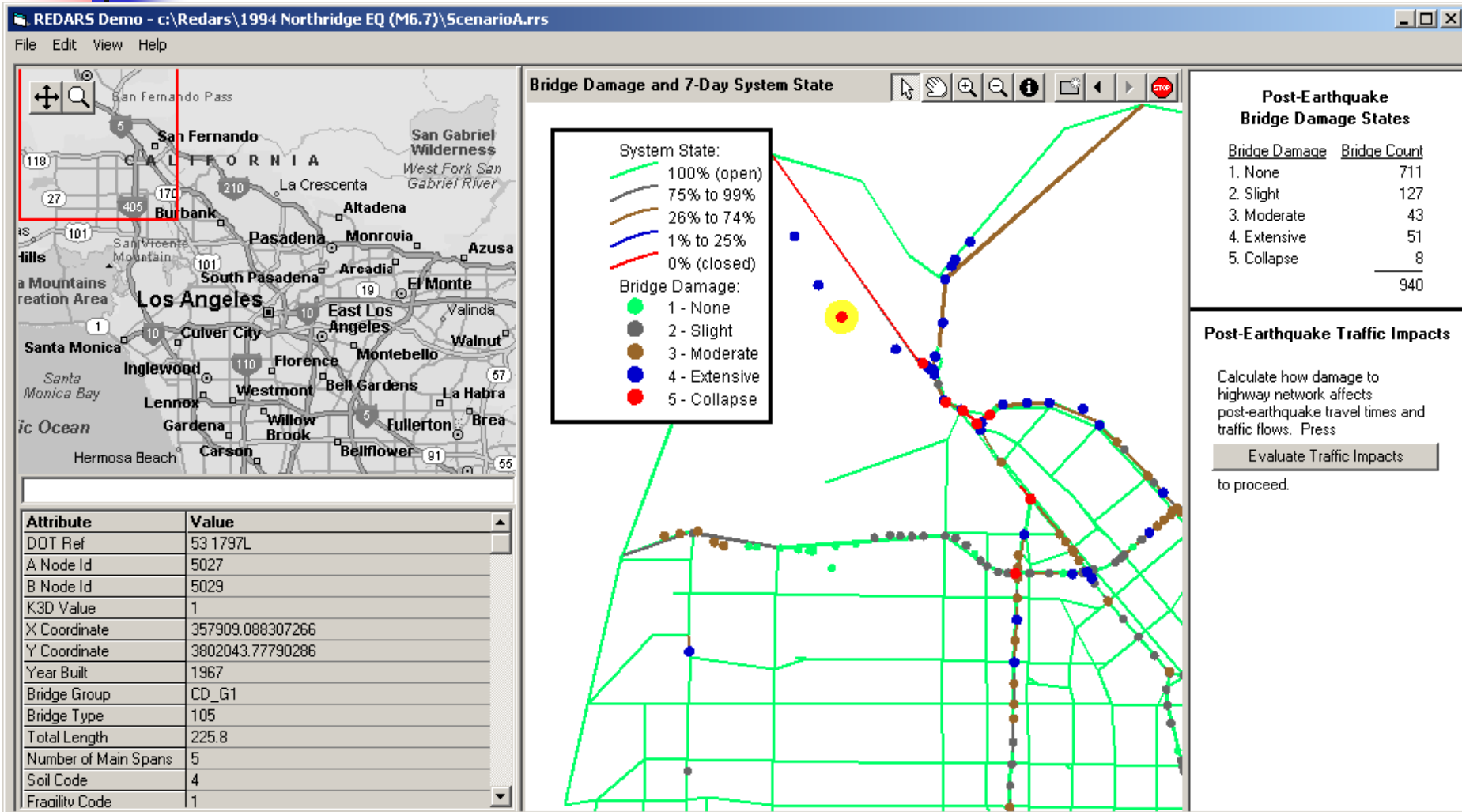
to proceed.

Attribute	Value
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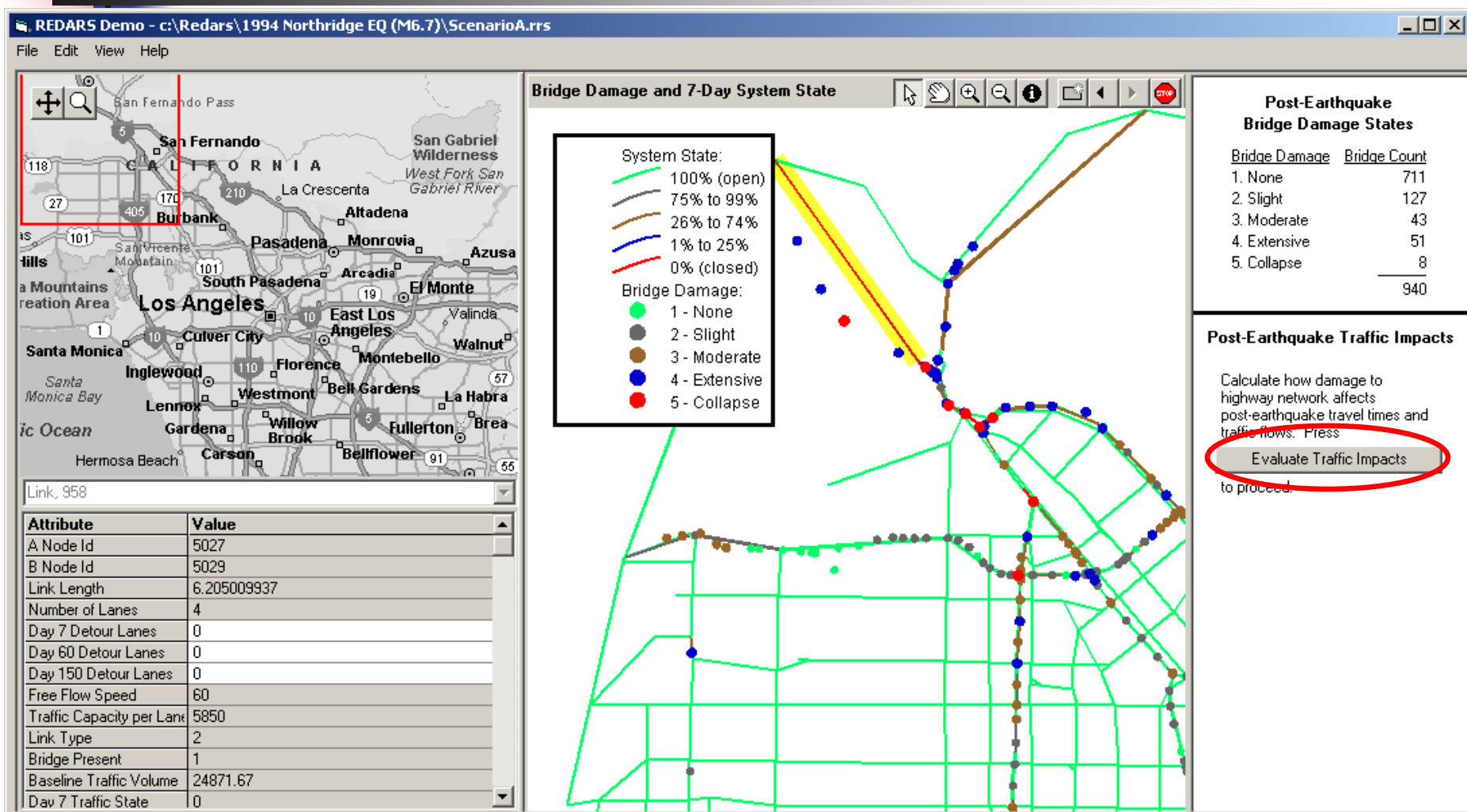
BRIDGE DAMAGE & SYSTEM STATES

7-DAYS AFTER EQ:

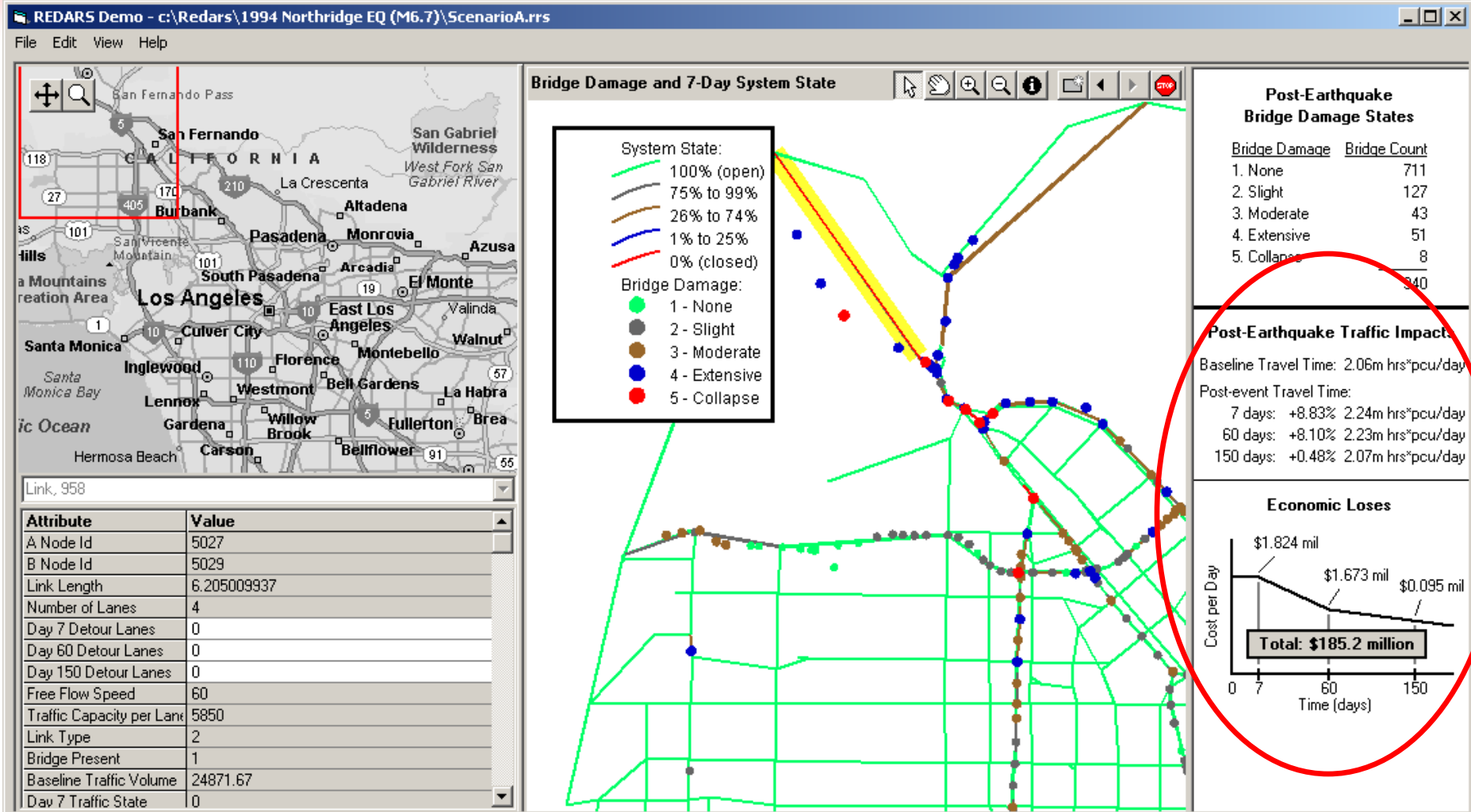
(INDIVIDUAL BRIDGE DATA DISPLAY)



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

REDARS Demo - c:\Redars\1994 Northridge EQ (M6.7)\ScenarioA.rrs

File Edit **View** Help

Map Views
 Map Legend
 Zoom To All
 Shortest Path...

Epicenter
 NEHRP Soil Types at Bridges
 Spectral Acceleration at 0.3 Seconds
 Spectral Acceleration at 1.0 Second
 Roadway Network (with Lane Mods)
 Baseline Traffic Volumes
 Bridge Damage and 7-Day System State
 Bridge Damage and 60-Day System State
 Bridge Damage and 150-Day System State
 Isolated Origin-Destination Zones

Traffic Volumes at 7 Days
 Traffic Volumes at 60 Days
 Traffic Volumes at 150 Days
 Access / Egress Times at 7 Days
 Access / Egress Times at 60 Days
 Access / Egress Times at 150 Days

Damage and 7-Day System State

System State:
 100% (open)
 75% to 99%
 26% to 74%
 1% to 25%
 0% (closed)

Bridge Damage:
 1 - None
 2 - Slight
 3 - Moderate
 4 - Extensive
 5 - Collapse

Post-Earthquake Bridge Damage States

Bridge Damage	Bridge Count
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5. Collapse	8
	<hr/> 940

Post-Earthquake Traffic Impacts

Baseline Travel Time: 2.06m hrs*pcu/day
 Post-event Travel Time:
 7 days: +8.83% 2.24m hrs*pcu/day
 60 days: +8.10% 2.23m hrs*pcu/day
 150 days: +0.48% 2.07m hrs*pcu/day

Economic Losses

Cost per Day

\$1.824 mil
 \$1.673 mil
 \$0.095 mil

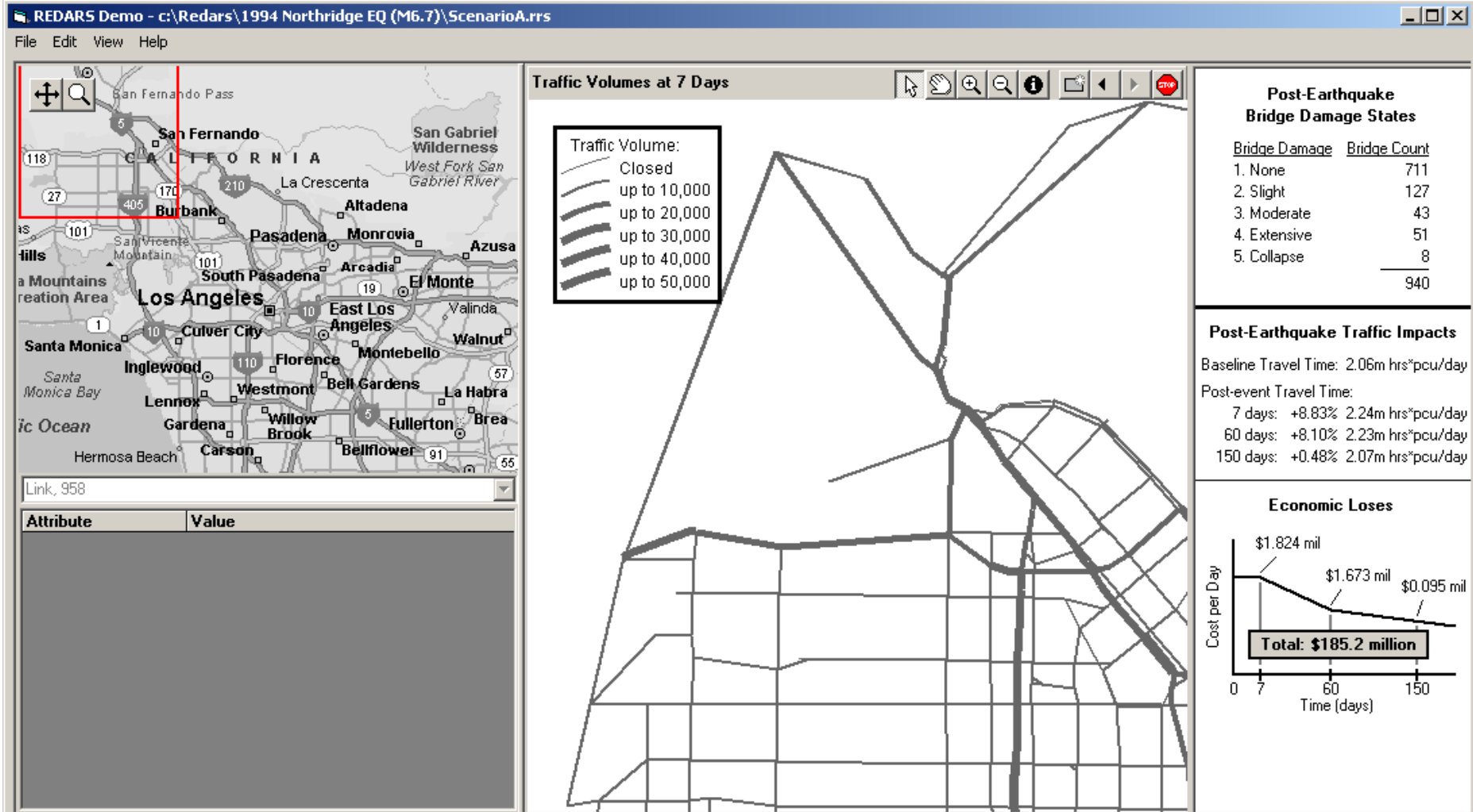
Total: \$185.2 million

Time (days)

Link, 958

Attribute	Value
A Node Id	5027
B Node Id	5029
Link Length	6.205009937
Number of Lanes	4
Day 7 Detour Lanes	0
Day 60 Detour Lanes	0
Day 150 Detour Lanes	0
Free Flow Speed	60
Traffic Capacity per Lane	5850
Link Type	2
Bridge Present	1
Baseline Traffic Volume	24871.67
Day 7 Traffic State	0

DISPLAY OF TRAFFIC VOLUMES 7-DAYS AFTER EQ



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

REDARS Demo - c:\Redars\1994 Northridge EQ (M6.7)\ScenarioA.rrs

File Edit **View** Help

Map Views
 Map Legend
 Zoom To All
 Shortest Path...

Epicenter
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 Traffic Volumes at 7 Days
 Traffic Volumes at 60 Days
 Traffic Volumes at 150 Days
Access / Egress Times at 7 Days
 Access / Egress Times at 60 Days
 Access / Egress Times at 150 Days

Volumes at 7 Days

Traffic Volume:
 Closed
 up to 10,000
 up to 20,000
 up to 30,000
 up to 40,000
 up to 50,000

Post-Earthquake Bridge Damage States

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1. None	711
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Economic Losses

Cost per Day

Time (days)

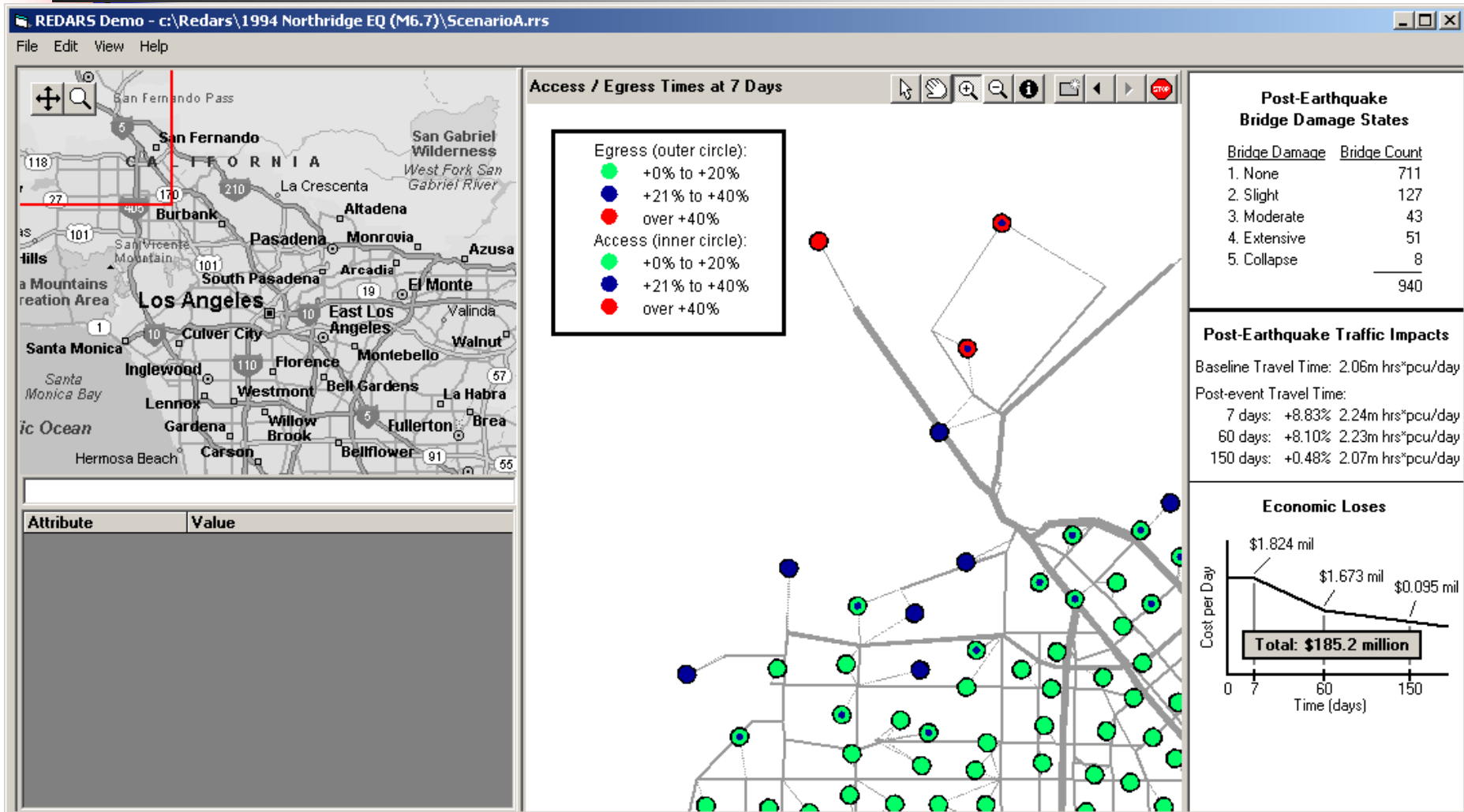
\$1.824 mil
 \$1.673 mil
 \$0.095 mil

Total: \$185.2 million

Link, 958

Attribute	Value
-----------	-------

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



UPDATING OF BRIDGE DAMAGE DATA IN REAL-TIME AFTER EQ

REDARS Demo - c:\Redars\1994 Northridge EQ (M6.7)\ScenarioA.rrs

File Edit View Help

Link, 958

Attribute	Value
ADT	0
Skew Angle	23
SS Type 1	0
SS Type 2	0
Number of Approach Sp.	0
State	CA
Spectral Acceleration at	2
Spectral Acceleration at	0.5
Damage State	5
Traffic State after 7 Days	0
Traffic State after 60 Day	0.25
Traffic State after 150 D.	0.75

Bridge Damage and 7-Day System State

System State:

- 100% (open)
- 75% to 99%
- 26% to 74%
- 1% to 25%
- 0% (closed)

Bridge Damage:

- 1 - None
- 2 - Slight
- 3 - Moderate
- 4 - Extensive
- 5 - Collapse

Post-Earthquake Bridge Damage States

Bridge Damage	Bridge Count
1. None	711
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4. Extensive	51
5. Collapse	8
Total	940

Post-Earthquake Traffic Impacts

Baseline Travel Time: 2.06m hrs*pcu/day

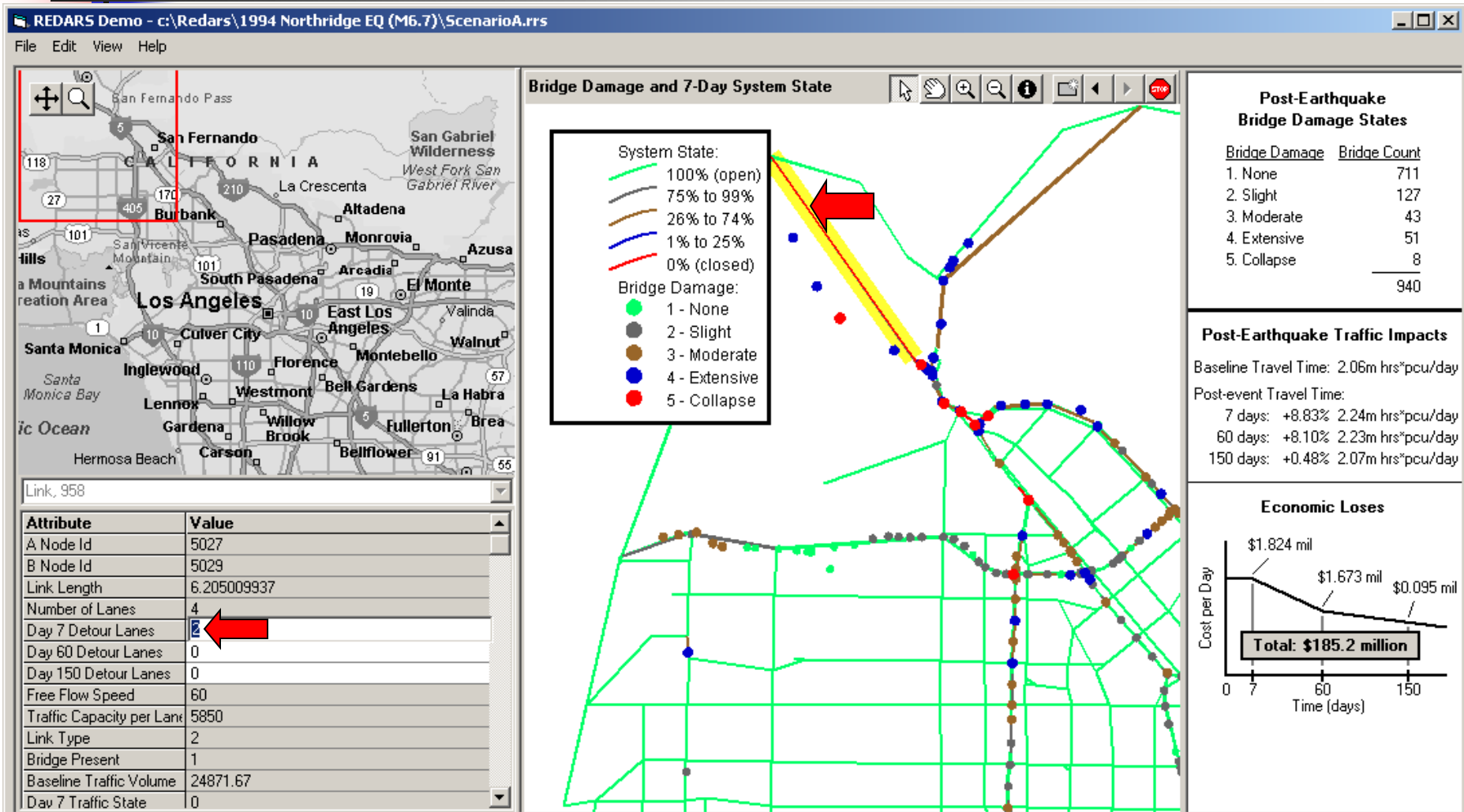
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Economic Losses

Total: \$185.2 million

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..

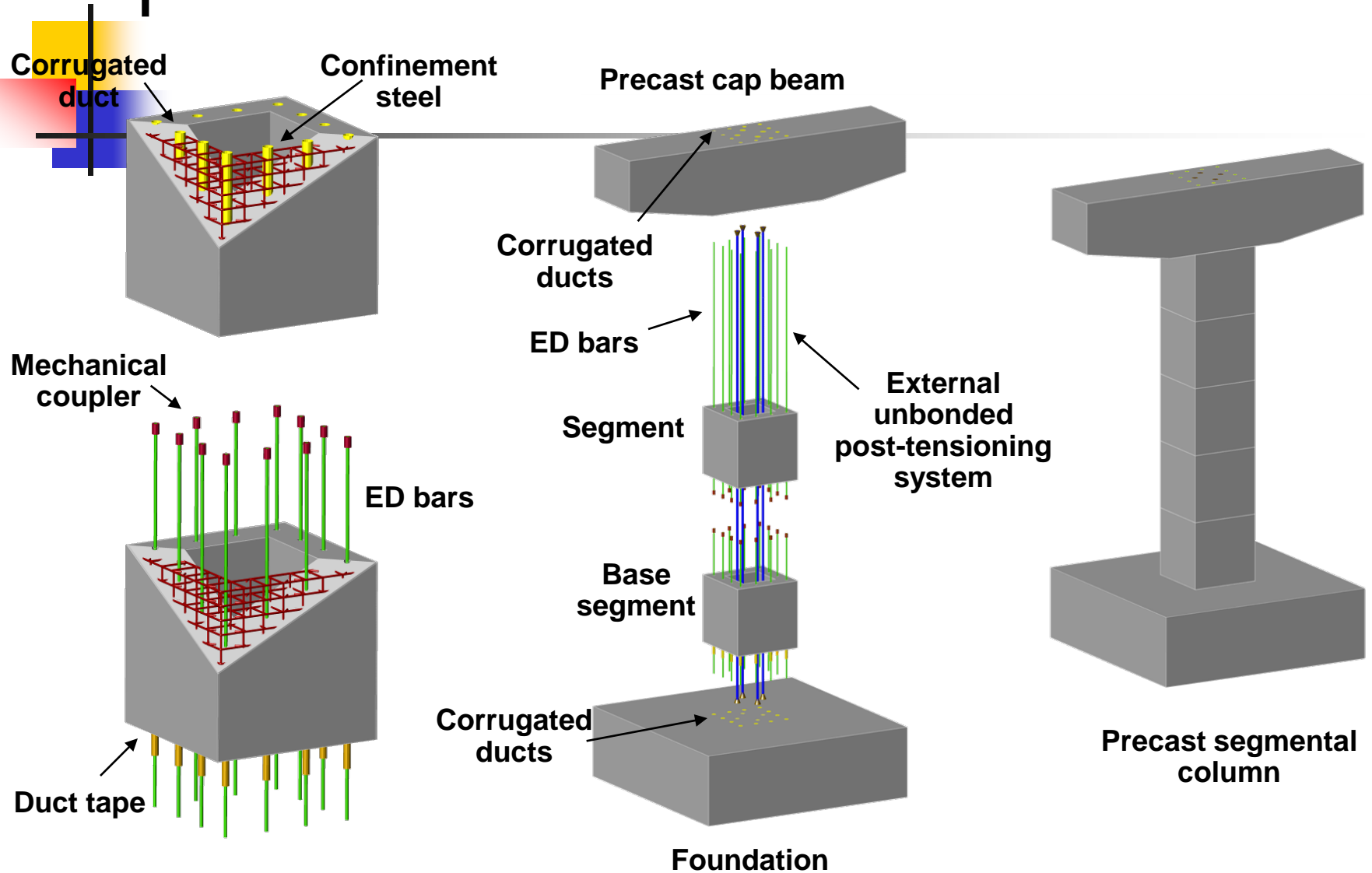




Seismic Research (Title V)

- 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



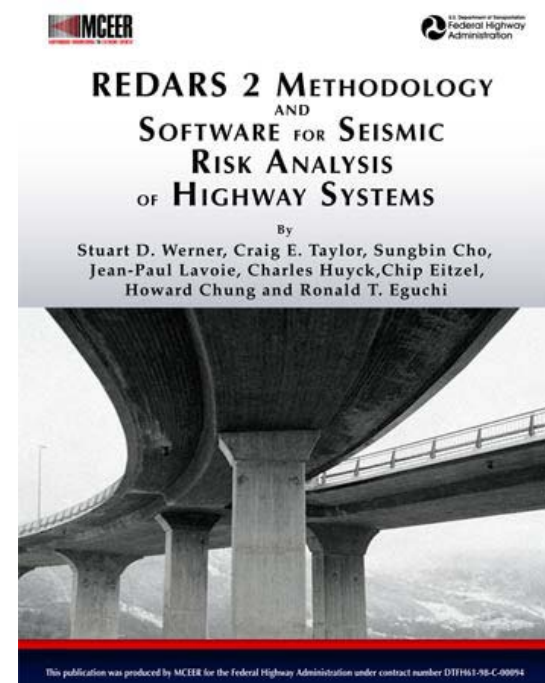


SAFETEA-LU

- 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

Calibration of LRFD
Design Code

NCHRP 368

Calibration of Load
Factors for Bridge
Evaluation

NCHRP 454

Design for
Extreme Events

NCHRP 489

**Scenario Based
Bridge Design**

FHWA Current Research Task

Next Edition AASHTO LRFD Specifications

(1999)

(2001)

(2003)

(2005)

Basic Parameter in Probability Based Approach

The Uniform Reliability Index

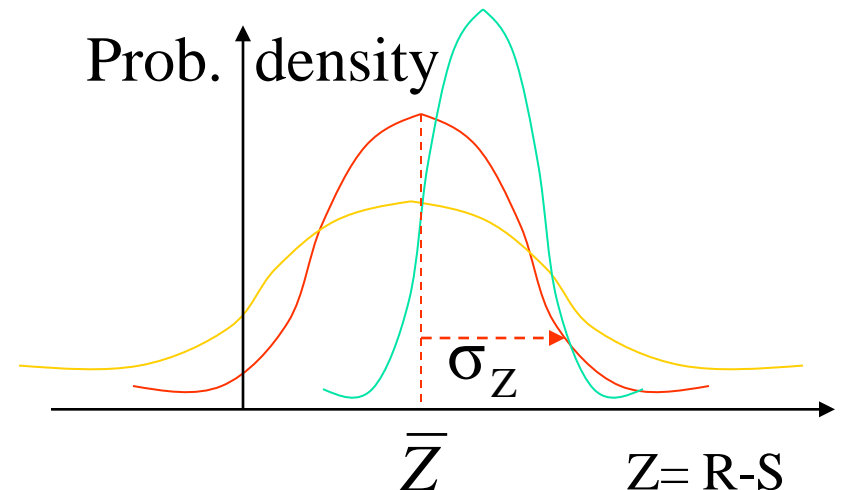
- Margin of safety

$$Z = R - S$$

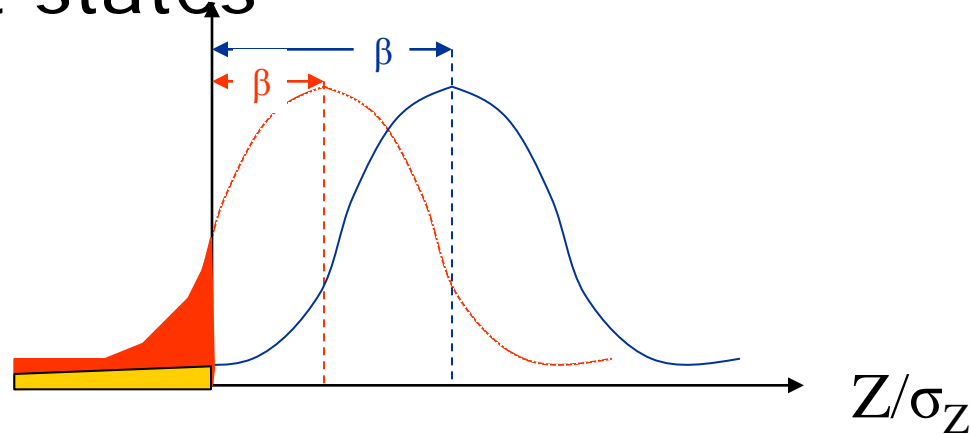
where R is the resistance and S is the loading

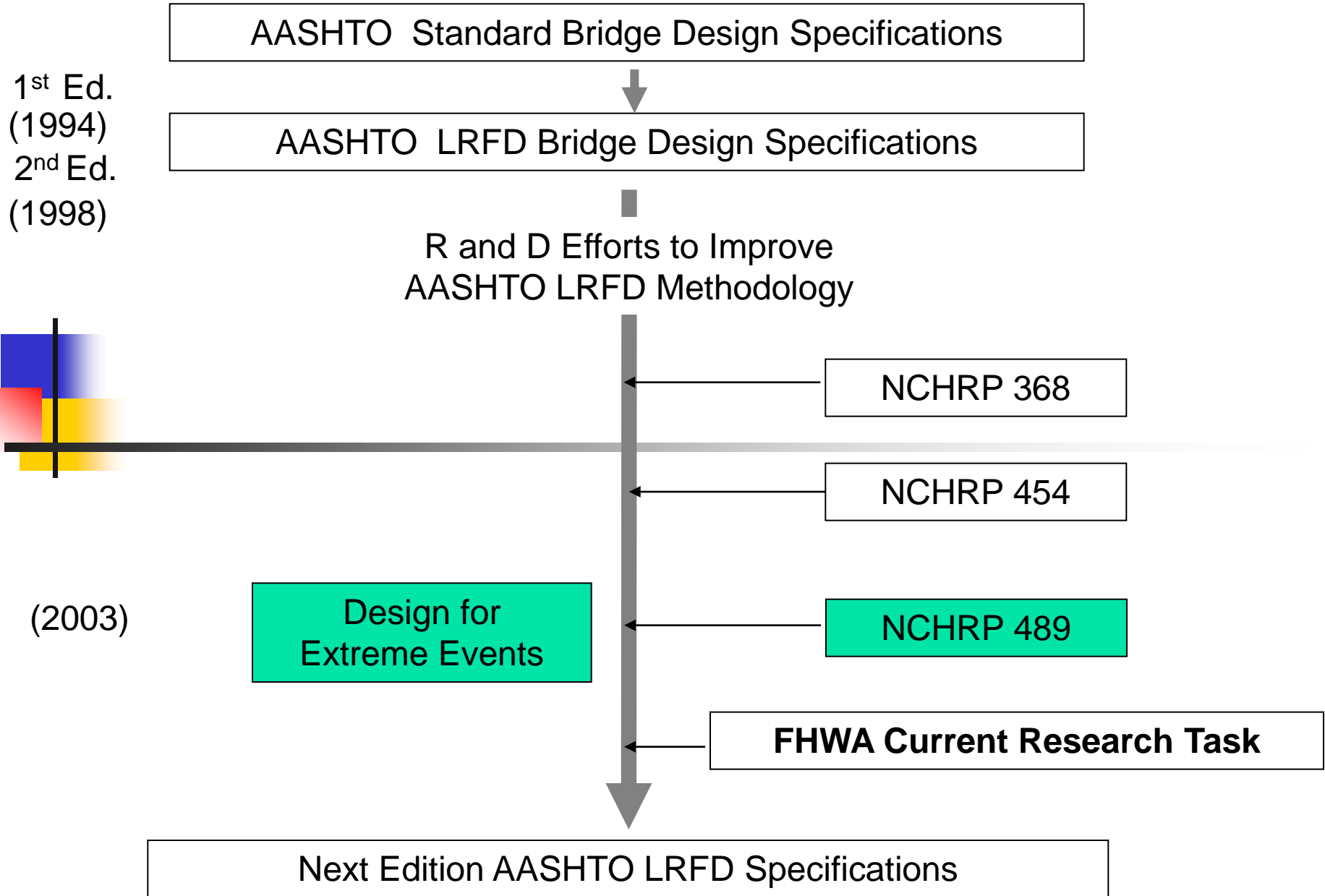
- Reliability Index

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



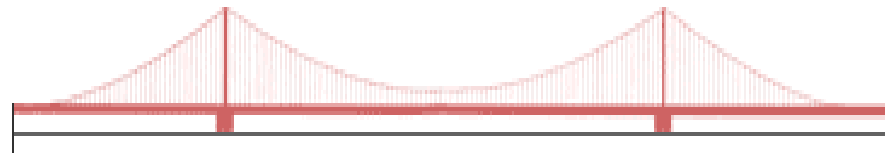
- β - Normalized probability measurement of reliability β for design limit states





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
