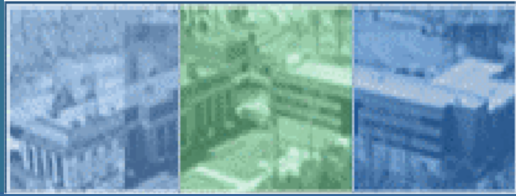
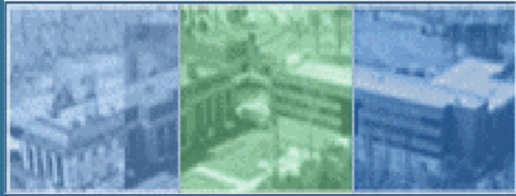


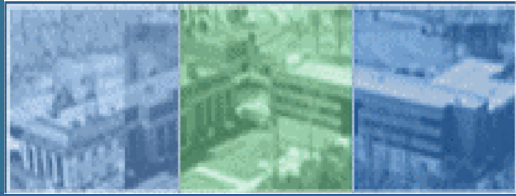
Seismic Hazard Mitigation Program for Highway Infrastructures

W. Phillip Yen, Ph.D., P.E.
Program Manager, Seismic Hazard Mitigation
Office of Infrastructure, R&D FHWA



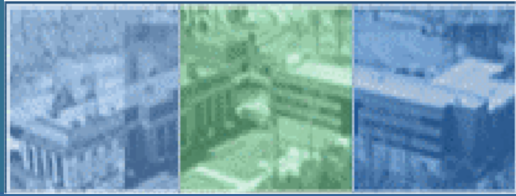
Outline

- Backgrounds
  - Risk Management & Hazard Mitigation
  - National Major Bridge Seismic Research – Under the ISTEA, TEA-21
- Retrofitting – Existing Bridges
  - Seismic Retrofitting Manual / Guidelines
- Designing – New Bridges
  - NCHRP 12-49 / LRFD Seismic Design Guide Spec.
- Planning – Risk Analysis & Loss Estimation
  - REDARS 2: Methodology and Software for Seismic Risk Analysis of Highway Systems
- Reconnaissance – Bridge Seismic Performance
- Current Research & National and International Cooperative Research Projects
- Transpotation Seismic Activities in Mid-America Area



US Highway Infrastructure Inventories

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



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?**

Seismic Research Prior to 1992

- Various seismic research projects in Design and Retrofittings
- Major Products:
  - Seismic Retrofitting Guidelines for Highway Bridges - *FHWA*/RD-83/007.
  - Seismic Design and Retrofitting Manual for Highway Bridges FHWA-IP-87-6
  - Full Scale Bridge Column Dynamic Testing – NIST – William Stone

Seismic Research Programs under ISTEA

- Two Seismic Vulnerability Studies were initiated in cooperation with Multidiscipline Center for Earthquake Engineering Research (MCEER).
  - Existing Bridges
    - Initiated 1992
    - $12 Millions/ 6 years
  - New Bridges
    - initiated 1993
    - $2.25 Millions/ 4 years

Research Tasks

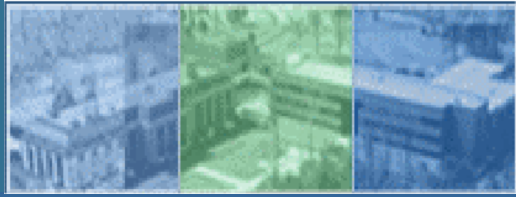
- Seismic Hazards and Ground Motions
- Geotechnical Engineering
- Structures and Systems
- Intelligent and Protective Systems
- Earthquake Reconnaissance
- Demonstration Projects
- Workshops and Conferences

TEA-21 : Seismic Vulnerability Study of Highway Systems

- Background:
  - Seismic Research Studies in New and Existing Highway Construction
    - Recommendations for Seismic Bridge Design Specifications.
    - Seismic Retrofitting Manual
  - Initiated 1998, $12 Million/ 6 years
- Objectives:
    - Transfer research results into practice
    - Refine and advance those final products
    - Expand and convert to design and construction specifications

Research Tasks

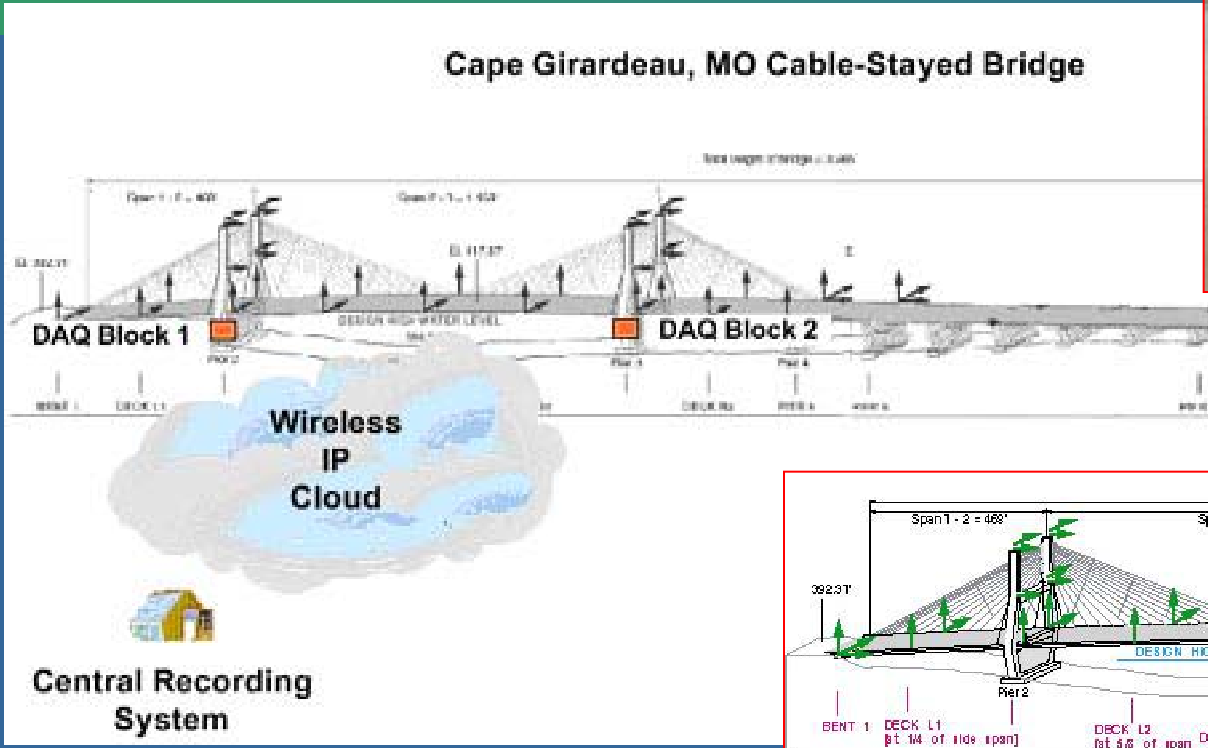
- Loss Estimation Methods for Highway Systems
- Seismic Design and Retrofit Manual for Long Span Bridges
- Earthquake Protective Systems
- Foundation and Geo-technical Studies
- Special Studies
- Technology Exchange and Transfer

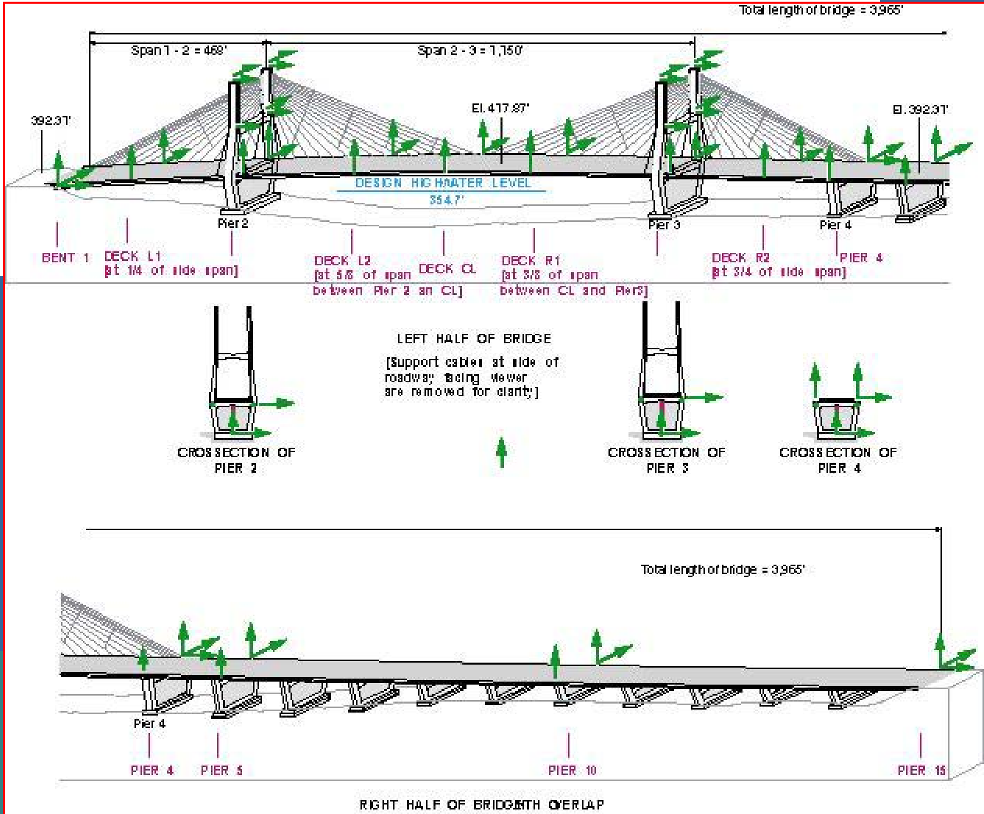


Special Studies

- Task of the project will address a series of special studies including:
  - Post-earthquake Nondestructive Assessment of Retrofitted Bridges
  - Cape Girardeau Cable-stayed Bridge Instrumentation
  - NCHRP Project 12-49 Supporting Studies
  - Earthquake Reconnaissance

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER





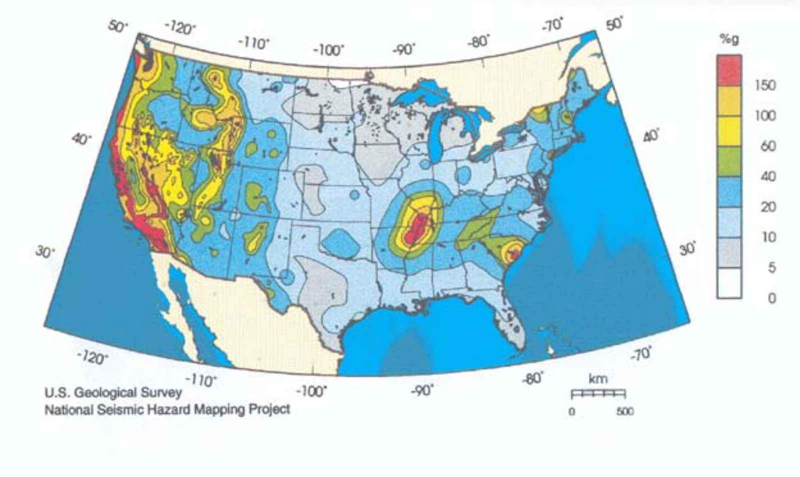
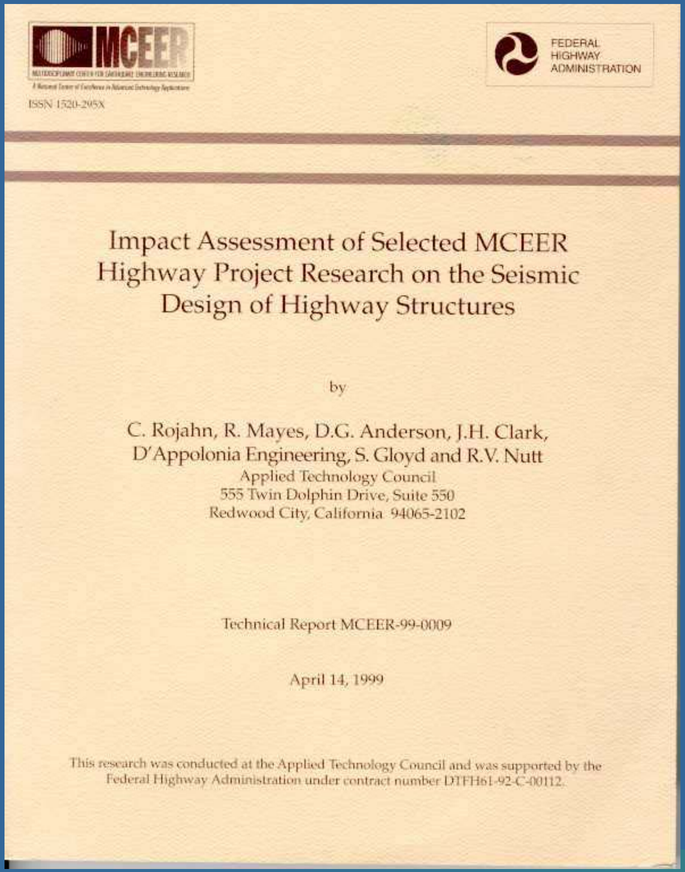


Figure 9a. MCE ground motion map of the 48 conterminous states for the 0.2 sec horizontal spectral response acceleration (%g), 5% of critical damping. Site Class B.

Mitigation Seismic Hazard through Designing

- Pre-San Fernando (1971)
  - 0.06g Static Coefficient
  - No Consideration For
    - Spectral Response
    - Foundation Material
    - Structural Ductility
- Today
  - Seismic Performance Criteria Identified

Development of Seismic Design Specifications


MCEER

FEDERAL HIGHWAY ADMINISTRATION

ISSN 1520-295X

Impact Assessment of Selected MCEER Highway Project Research on the Seismic Design of Highway Structures

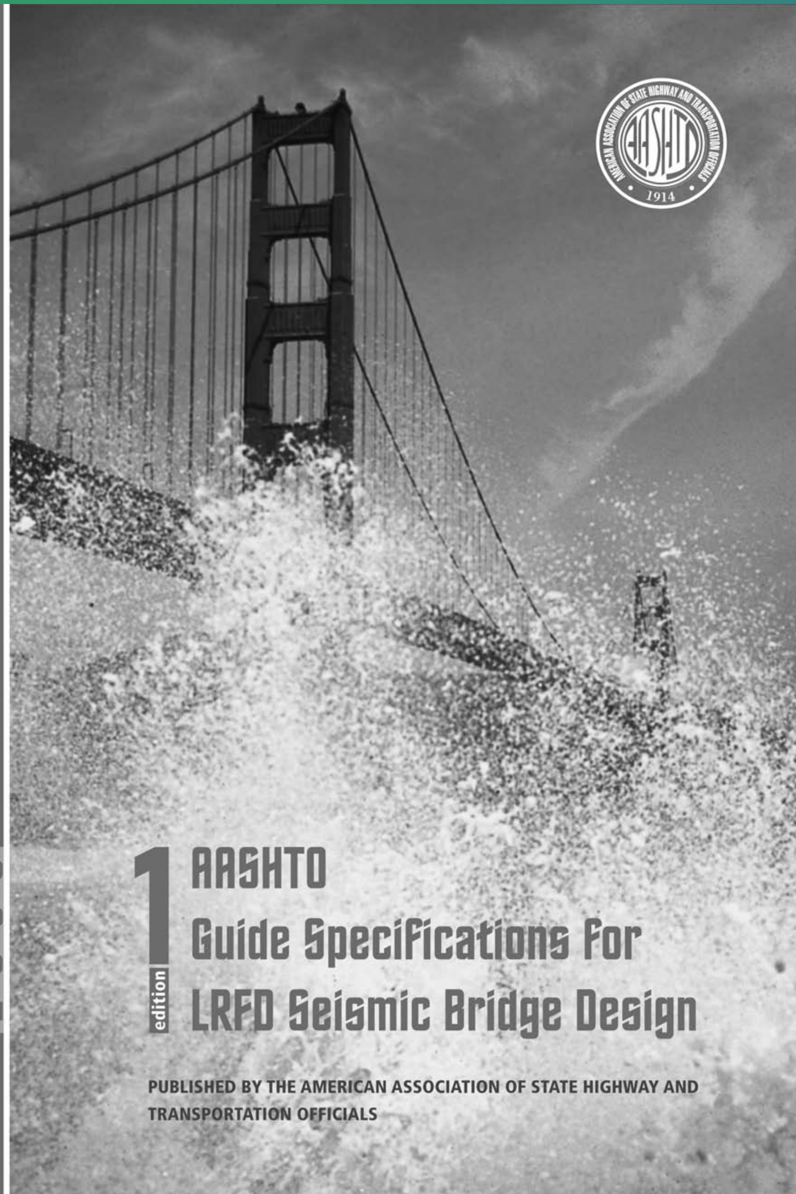
by

C. Rojahn, R. Mayes, D.G. Anderson, J.H. Clark, D'Appolonia Engineering, S. Gloyd and R.V. Nutt
Applied Technology Council
555 Twin Dolphin Drive, Suite 550
Redwood City, California 94065-2102

Technical Report MCEER-99-0009

April 14, 1999

This research was conducted at the Applied Technology Council and was supported by the Federal Highway Administration under contract number DTFH61-92-C-00112.



ABBREVIATED TABLE OF CONTENTS

PERFORMANCE CRITERIA

- Bridges shall be designed for the **life safety** performance objective considering a seismic hazard corresponding to a **7% probability of exceedance in 75 years. i.e. – 1000 Yr.** for "Normal Bridges".
- Higher levels of performance, such as the operational objective, may be established and authorized by of the bridge owner.

Life safety

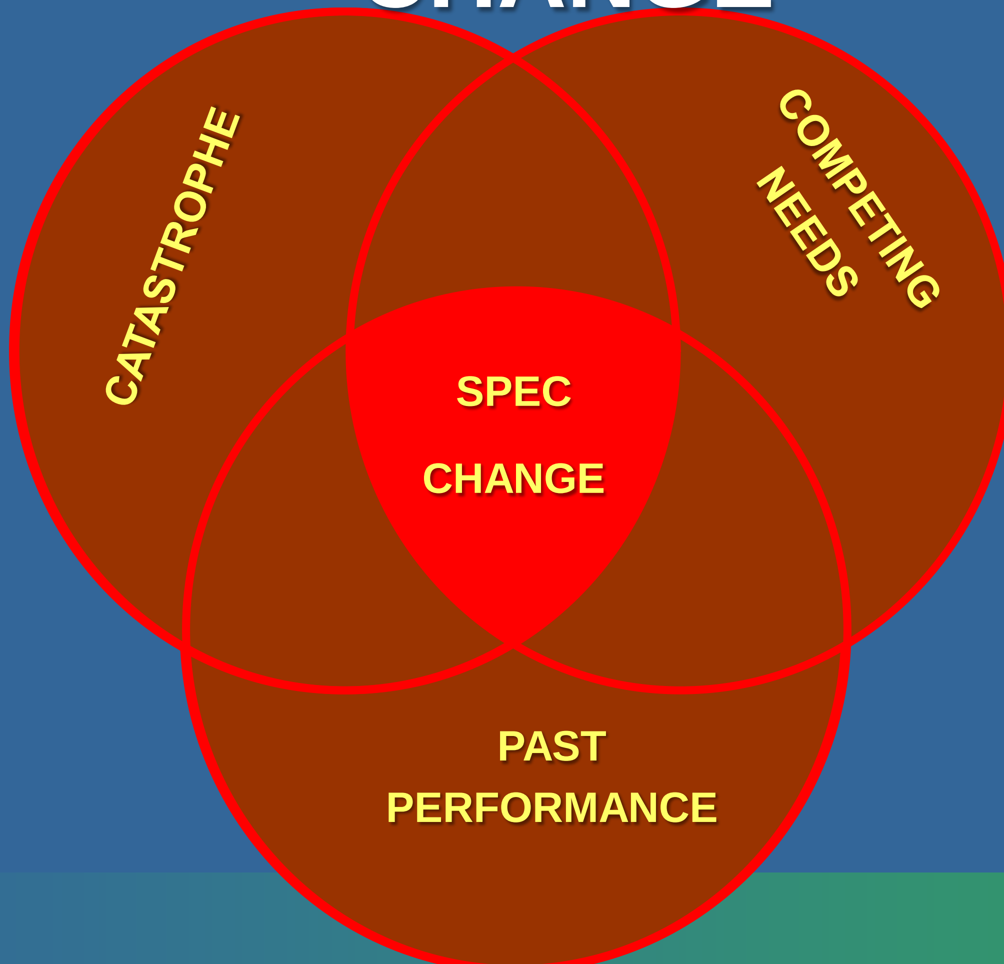
- Low probability of collapse but, may suffer significant damage and significant disruption to service is possible.
  - cracking,
  - reinforcement yielding,
  - major spalling of concrete
  - extensive yielding and local buckling of steel columns,
  - global and local buckling of steel braces, and
  - cracking in the bridge deck slab at shear studs.

SEISMIC DESIGN CATEGORY (SDC)

- Partitions for Seismic Design Categories A, B, C & D

Value of $SD_1 = F_v S_1$	SDC
$SD_1 < 0.15$	A
$0.15 \leq SD_1 < 0.30$	B
$0.30 \leq SD_1 < 0.50$	C
$0.50 \leq SD_1$	D

IMPLEMENTING SPECIFICATION CHANGE

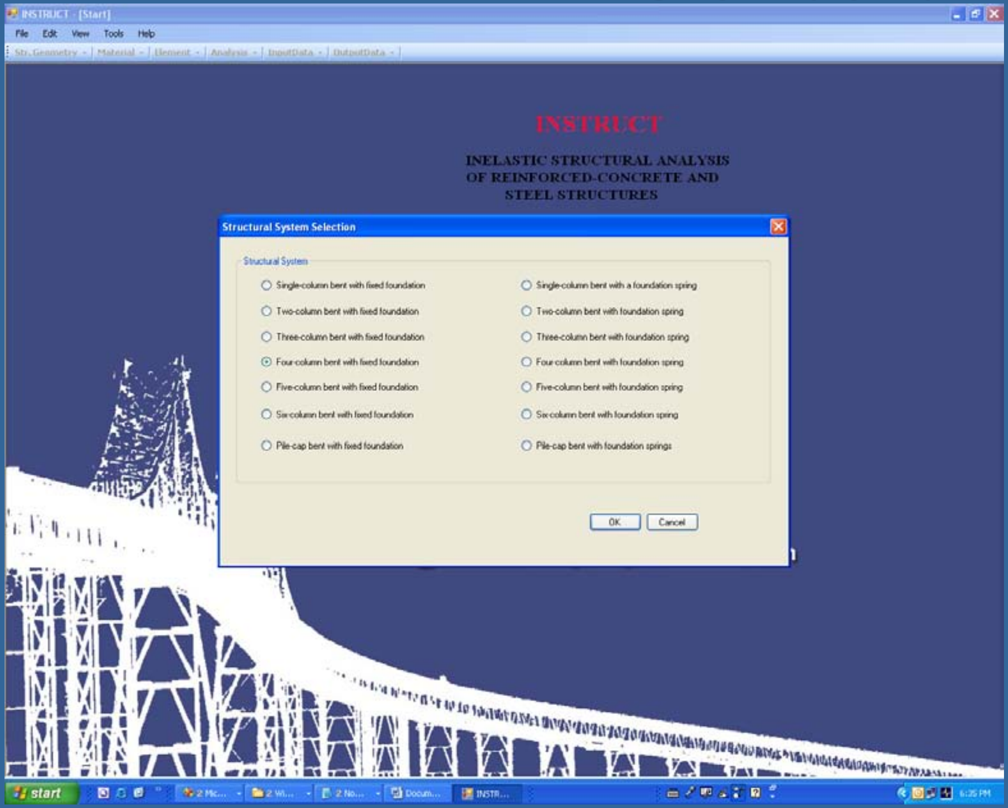


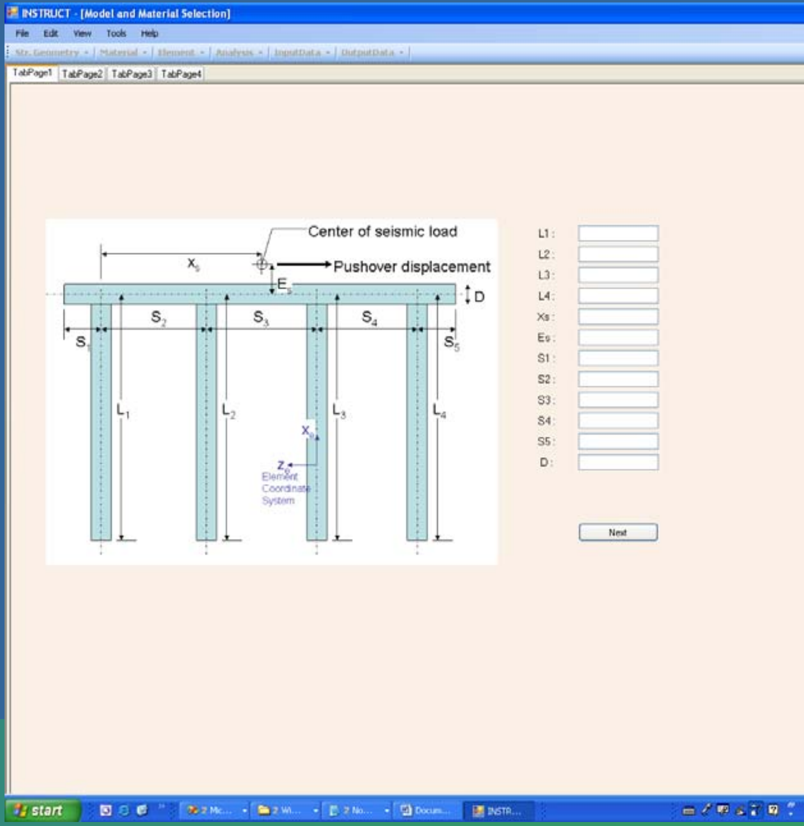
INSTRUCT Pushover Analysis Program

OBJECTIVE

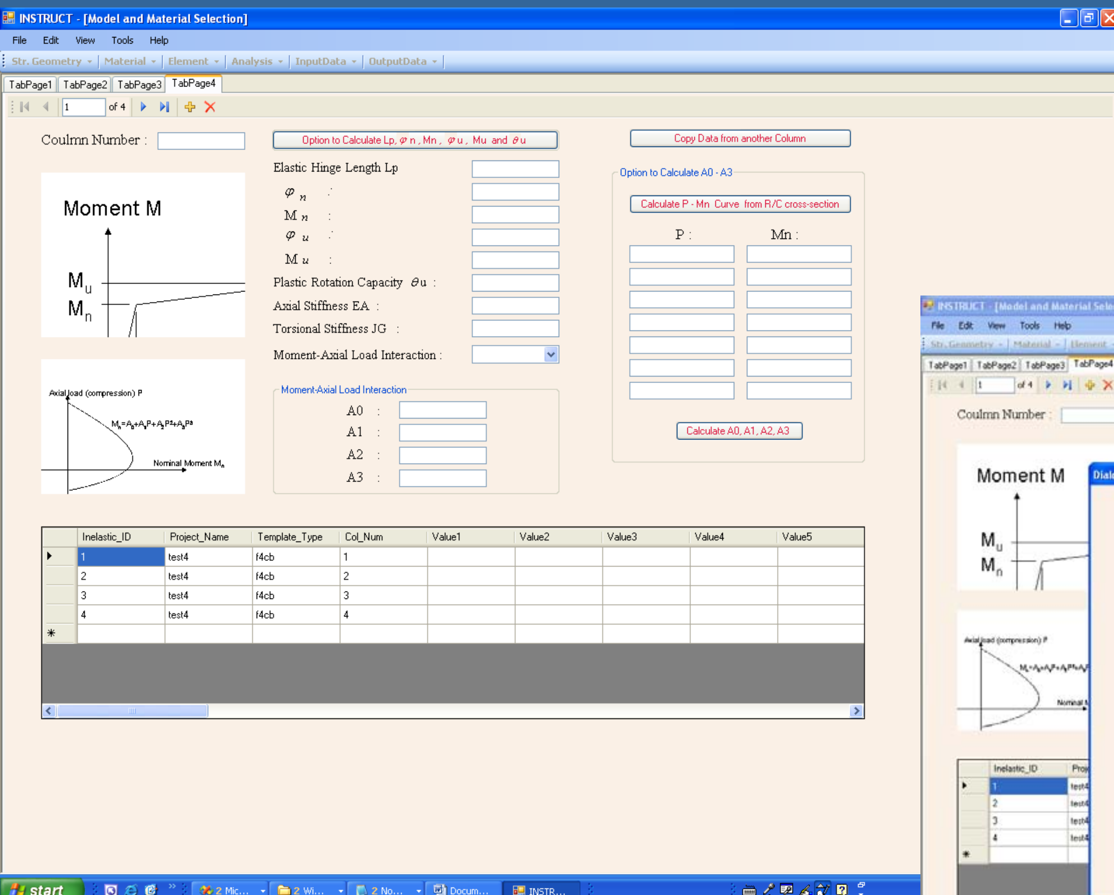
- This project aims to develop a window-based user-friendly interface for the current developed inelastic structural pushover analysis FORTRAN computer program. The ultimate goal is to provide State DOTs a useful tool (not a mandated tool) for the pushover analysis of highway bridges.

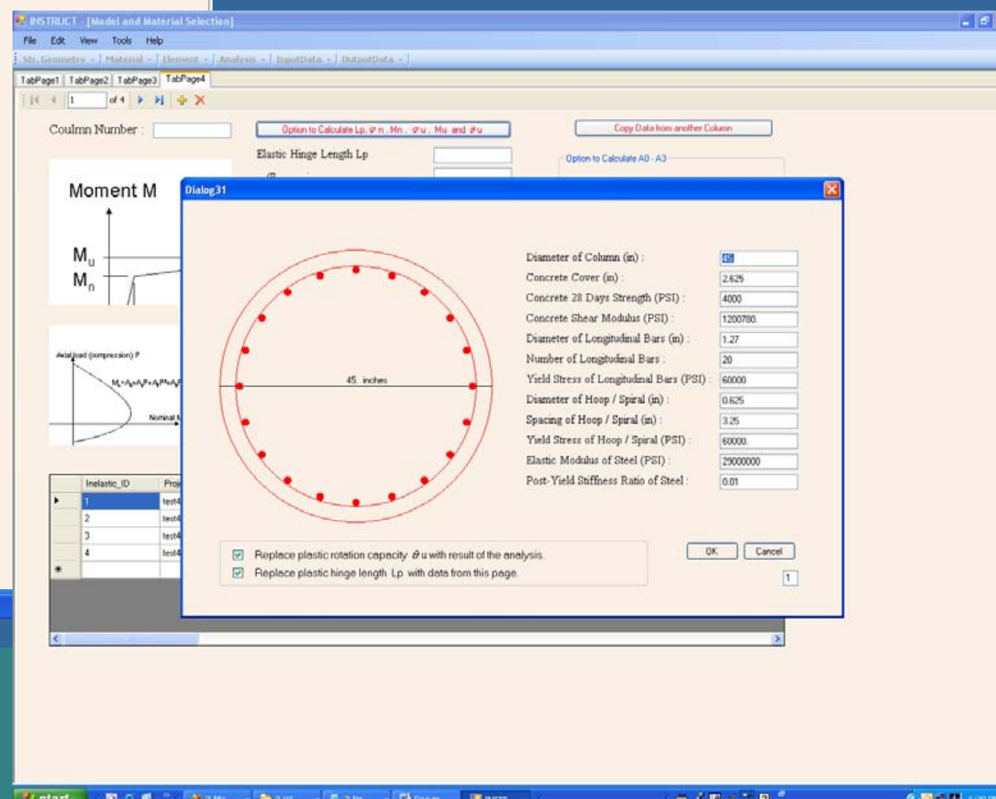
Standard Program



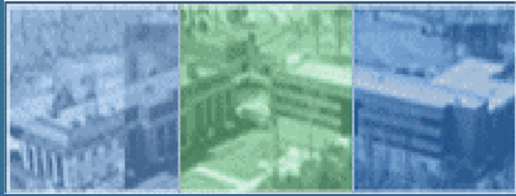


Standard Program



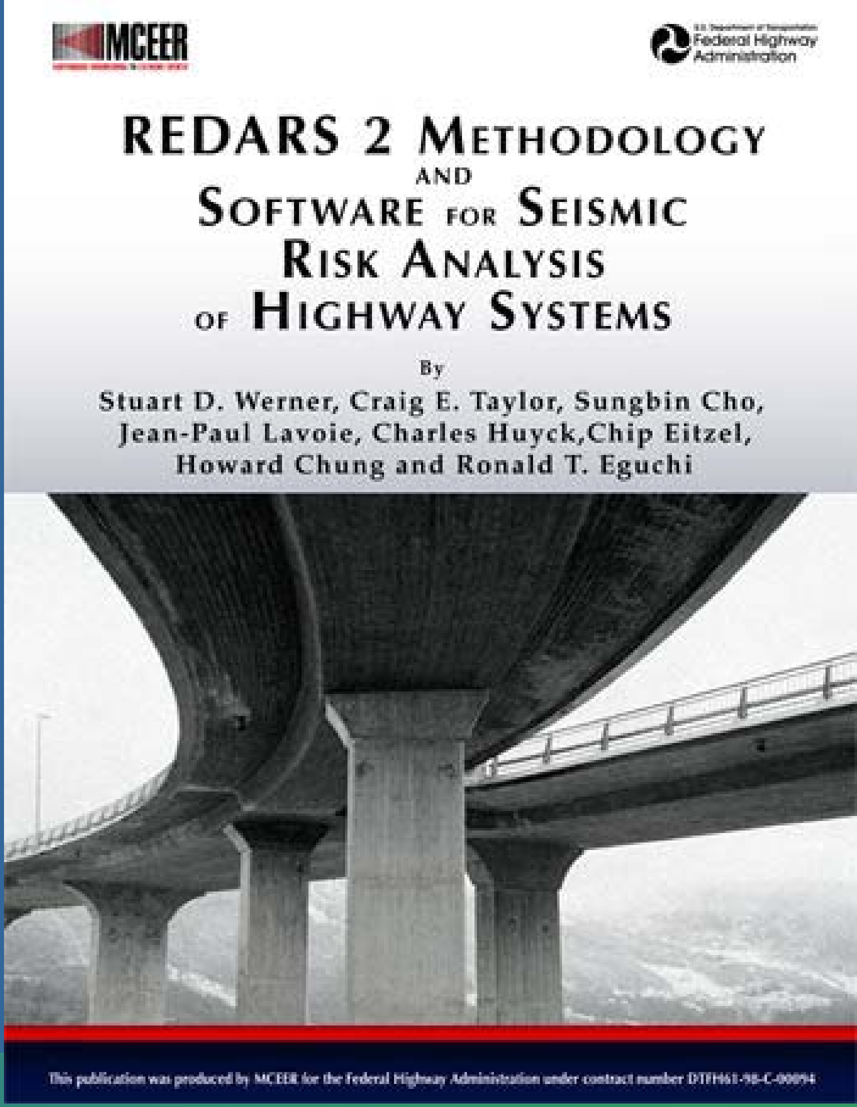


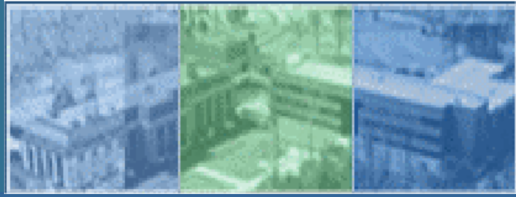
Mitigation Seismic Hazard through Planning



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.

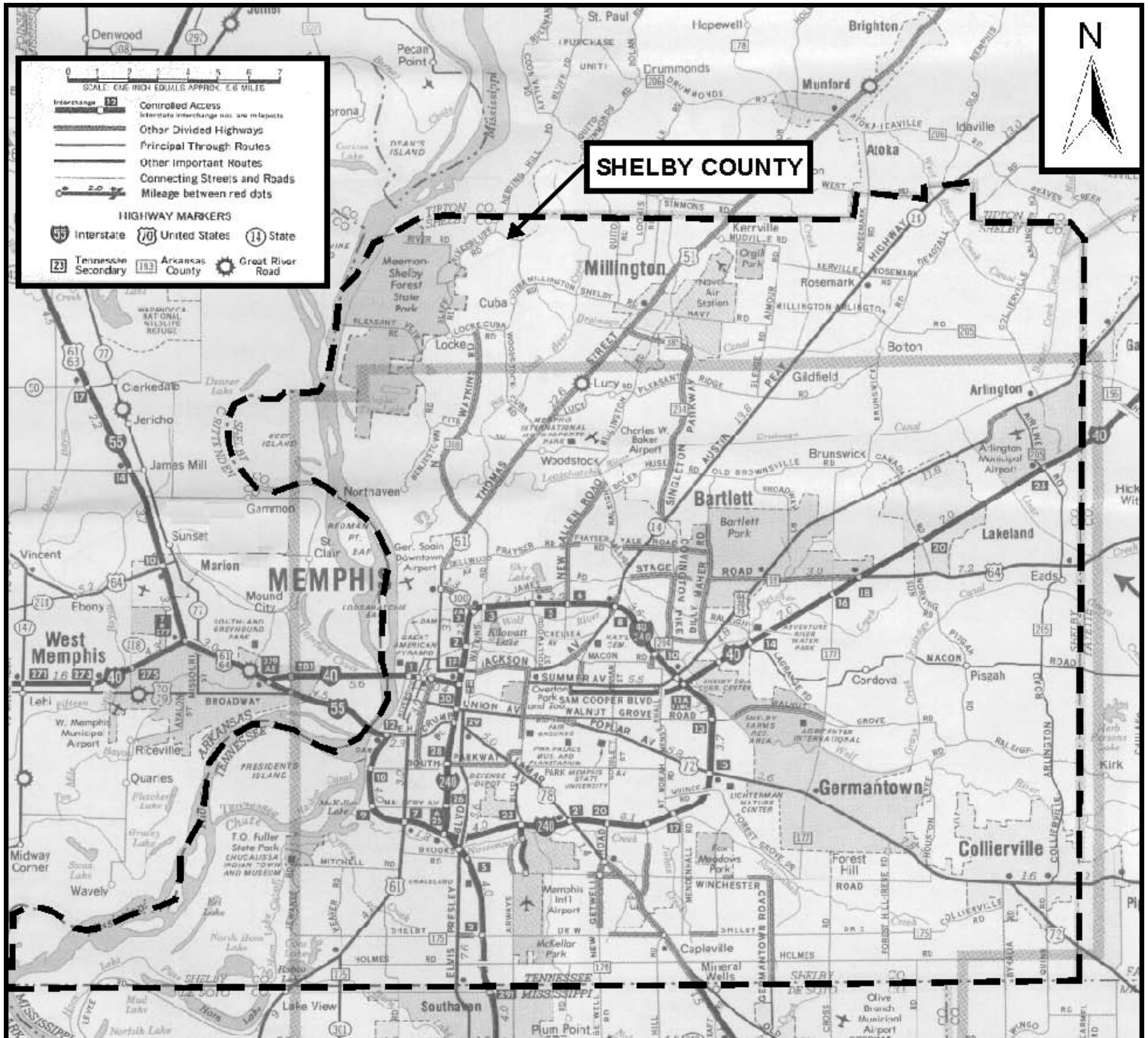




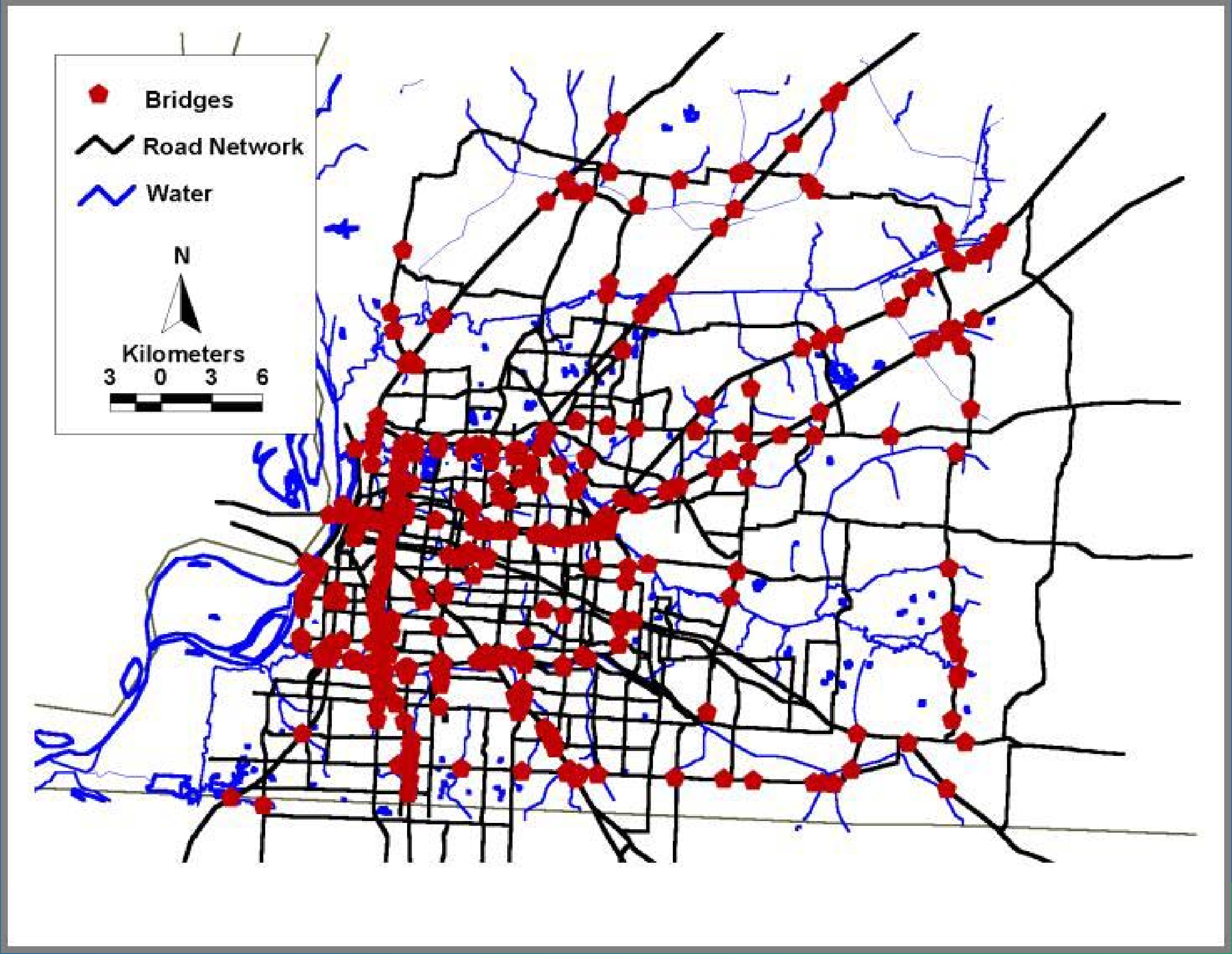
REDARS SOFTWARE: DESCRIPTION

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

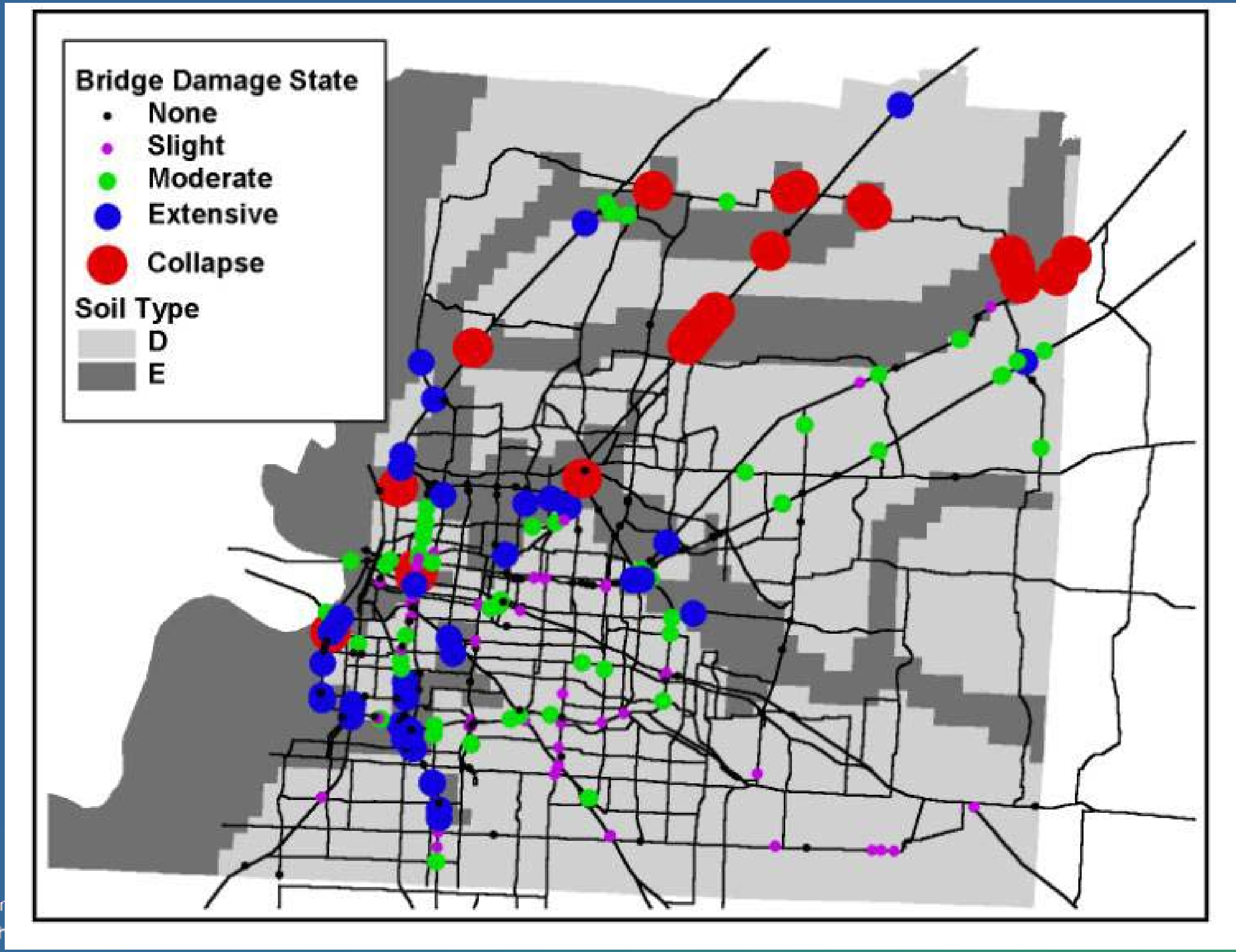
SHELBY COUNTY, TENNESSEE

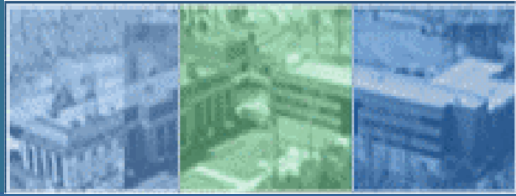


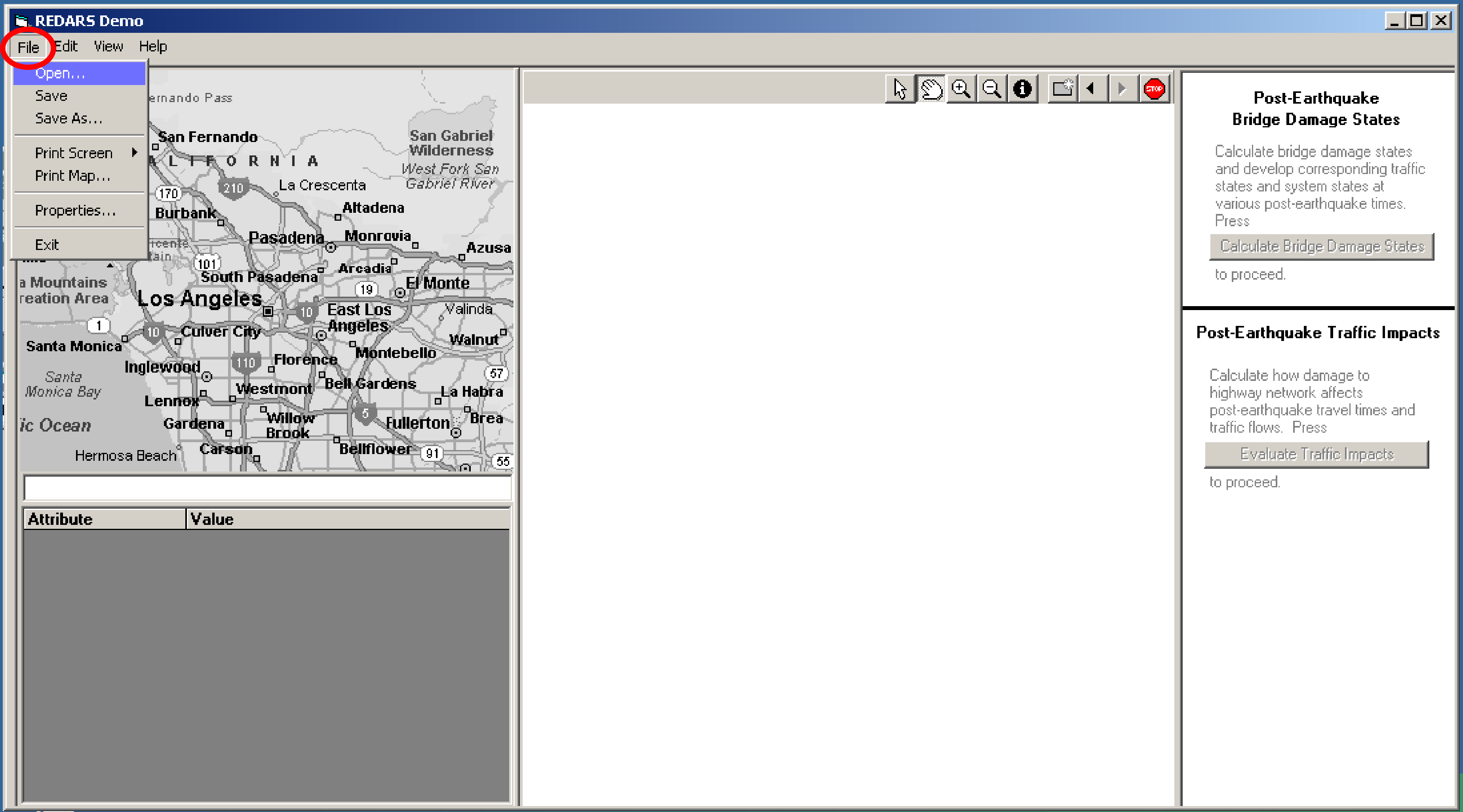
INPUT DATA: BRIDGES



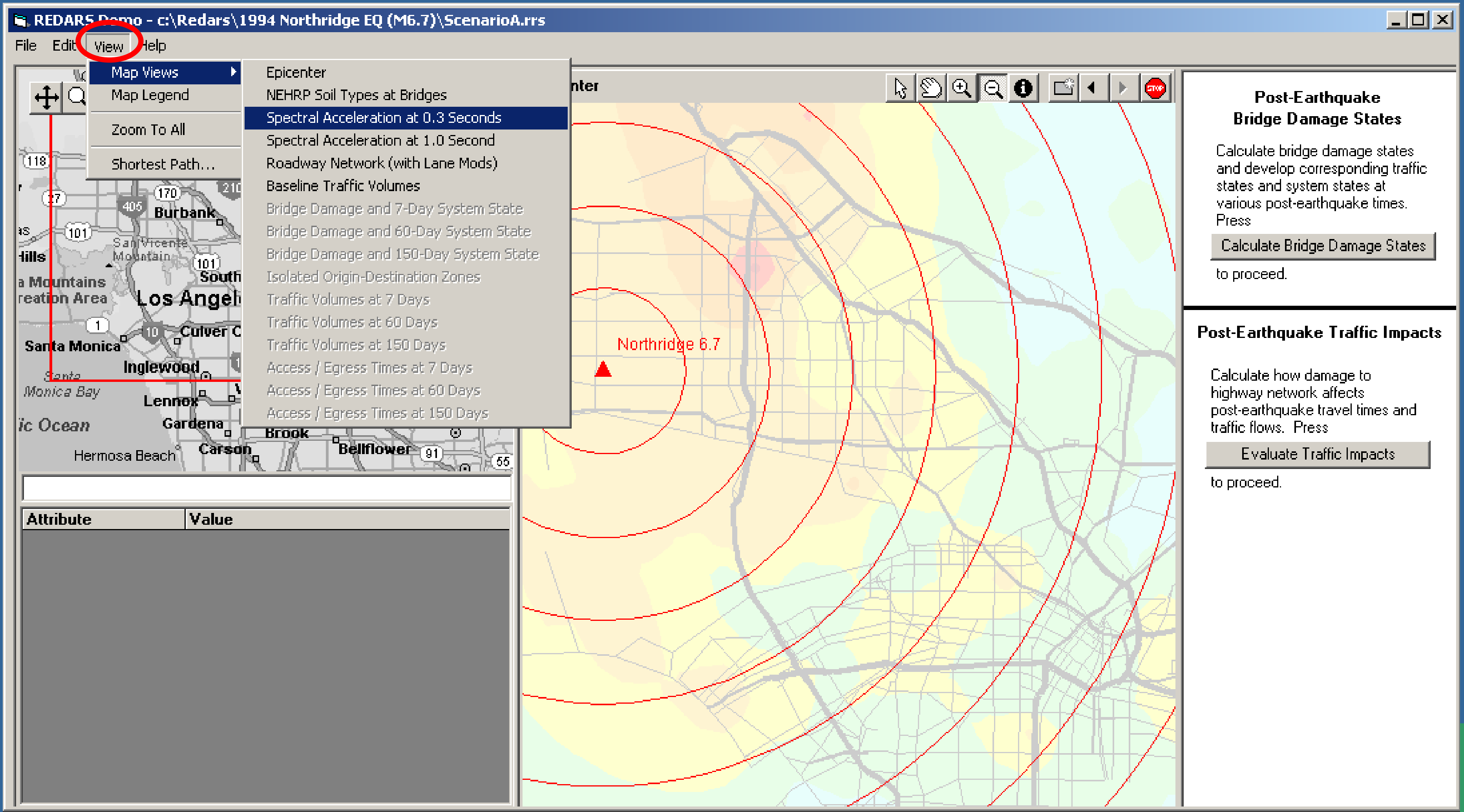
BRIDGE DAMAGE STATES



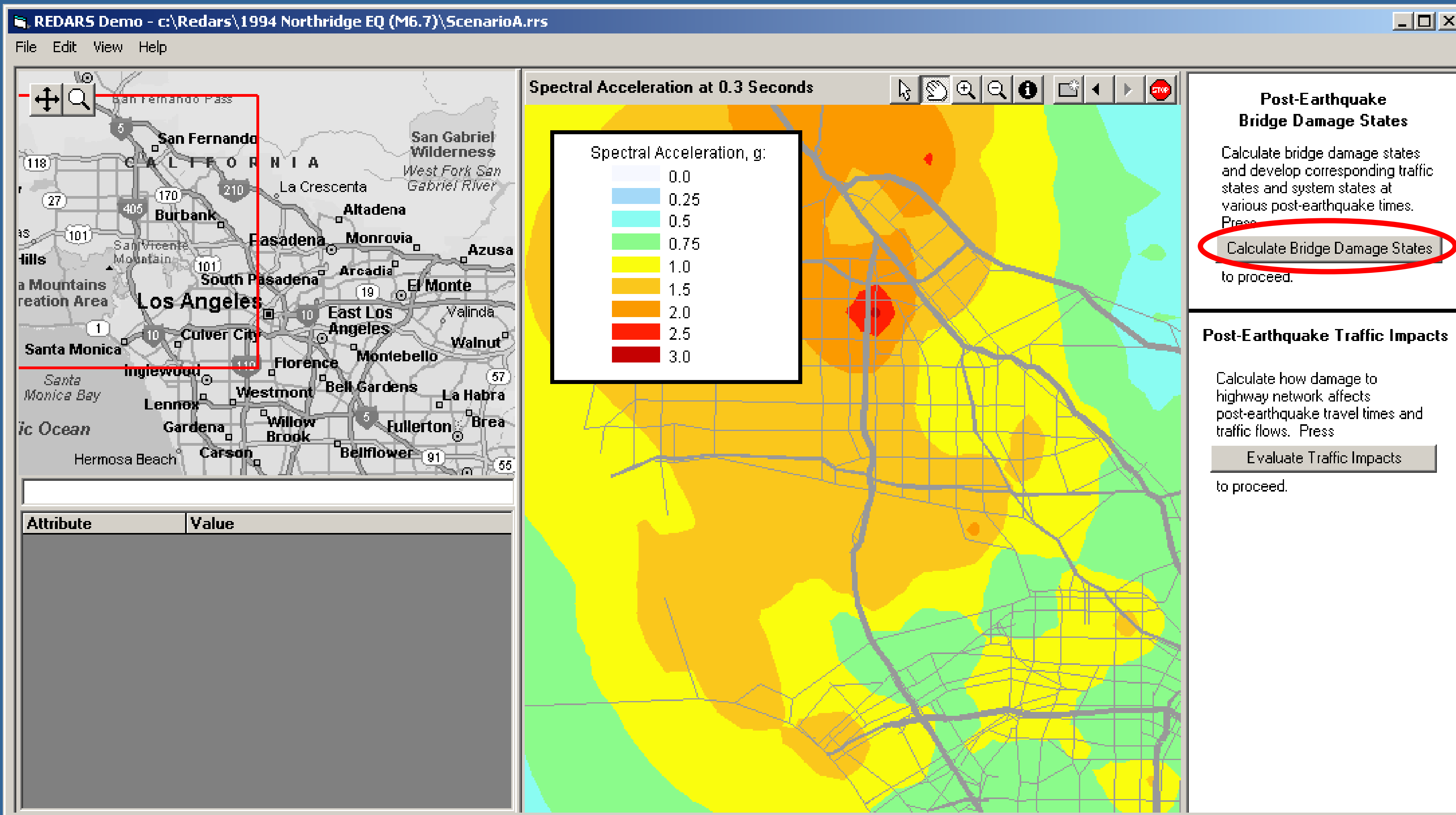


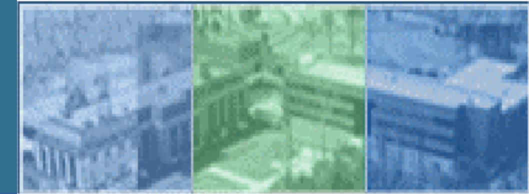

REDARS Demo
File
Edit
View
Help
Open...
Save
Save As...
Print Screen
Print Map...
Properties...
Exit
San Fernando
La Crescenta
San Gabriel Wilderness
West Fork San Gabriel River
Burbank
Altadena
Pasadena
Monrovia
Azusa
South Pasadena
Arcadia
El Monte
Los Angeles
East Los Angeles
Valinda
Culver City
Walnut
Santa Monica
Montebello
Florence
Inglewood
Santa Monica Bay
Westmont
Bell Gardens
La Habra
Lennox
Willow Brook
Brea
Gardena
Fullerton
Hermosa Beach
Carson
Bellflower
Attribute
Value
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.

DROP-DOWN MENU: ACCESS OF GROUND MOTION DATA

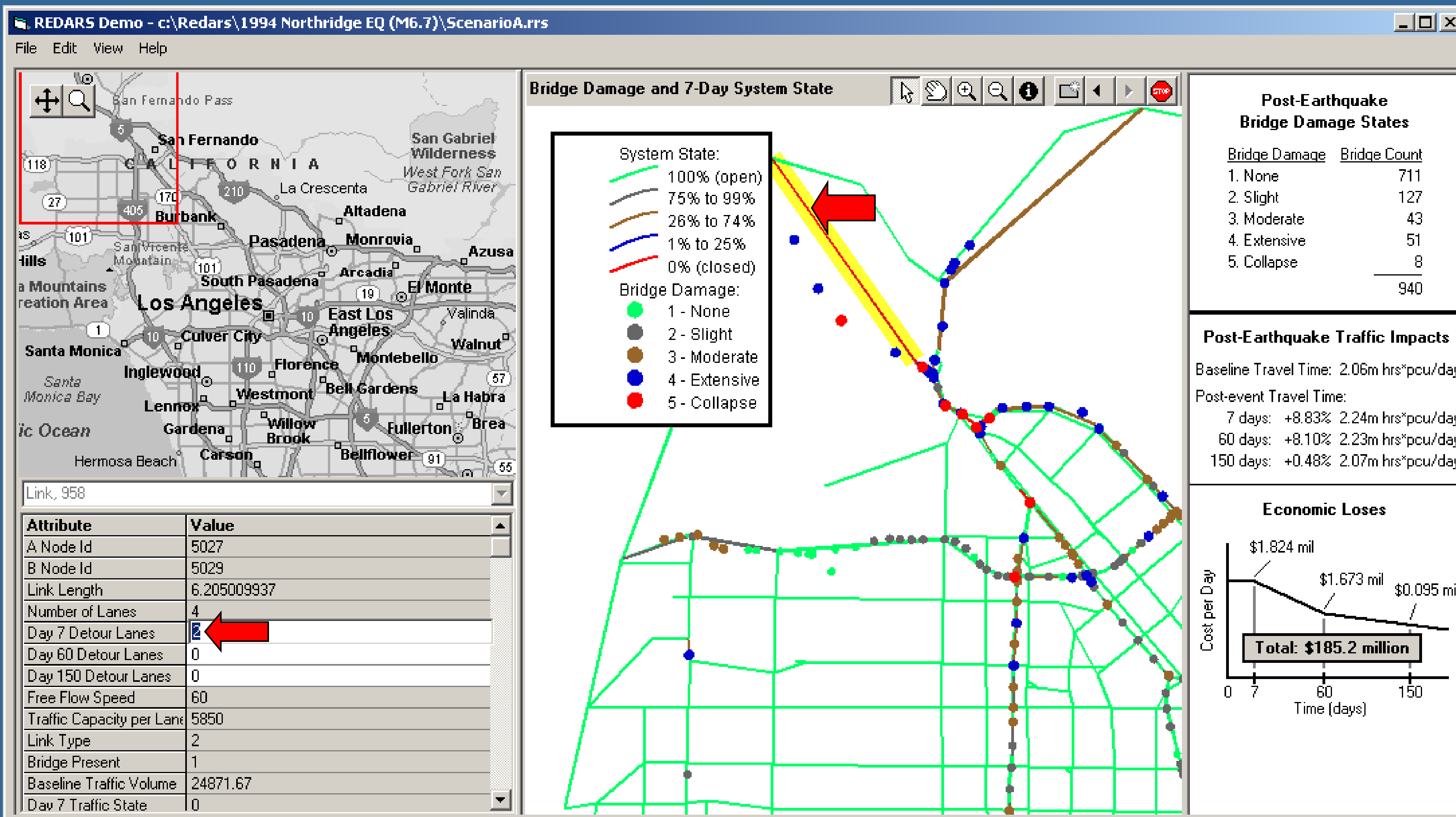


DISPLAY OF GROUND MOTIONS: SPECTRAL ACCELERATIONS AT T = 0.3 SEC.

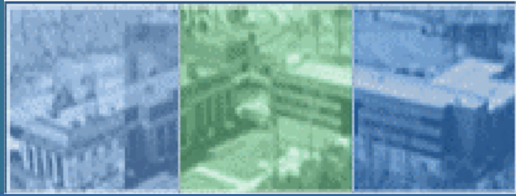




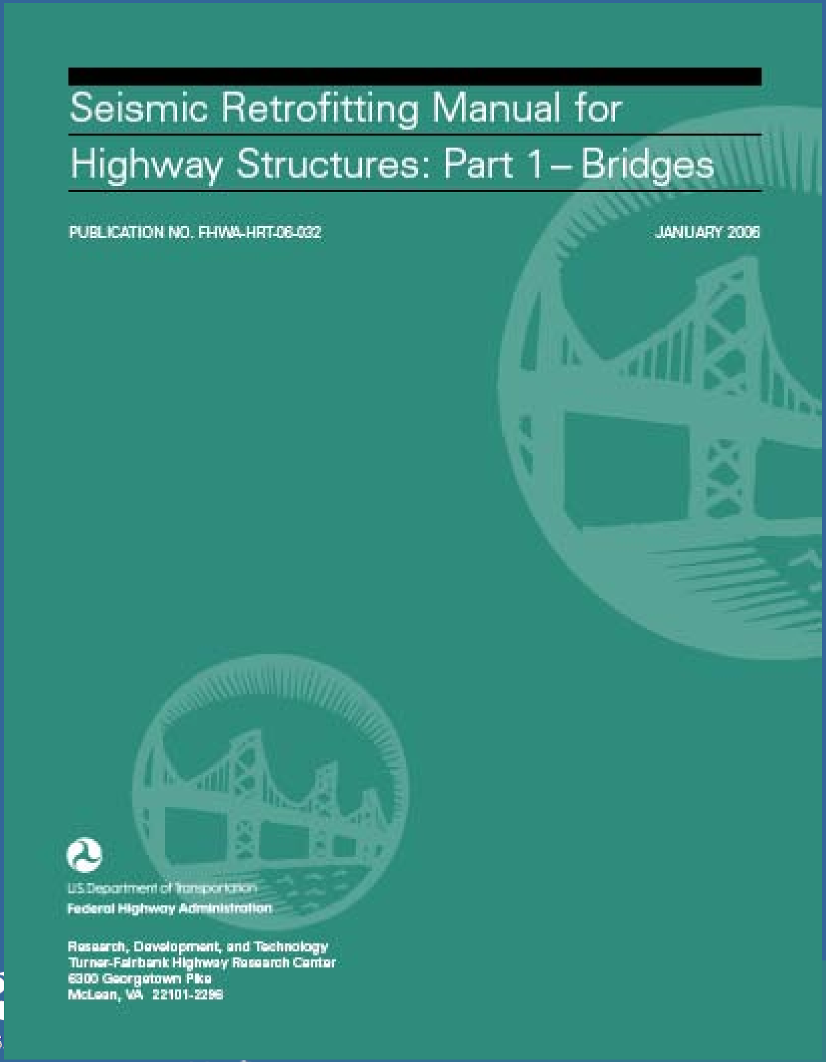
REAL-TIME ASSESSMENT OF ALTERNATIVE EMERGENCY RESPONSE STRATEGIES: (ADD DETOUR LINK ALONGSIDE DAMAGED BRIDGE)



Mitigation Seismic Hazard through Retrofitting



NEW FHWA Seismic Retrofitting Manuals

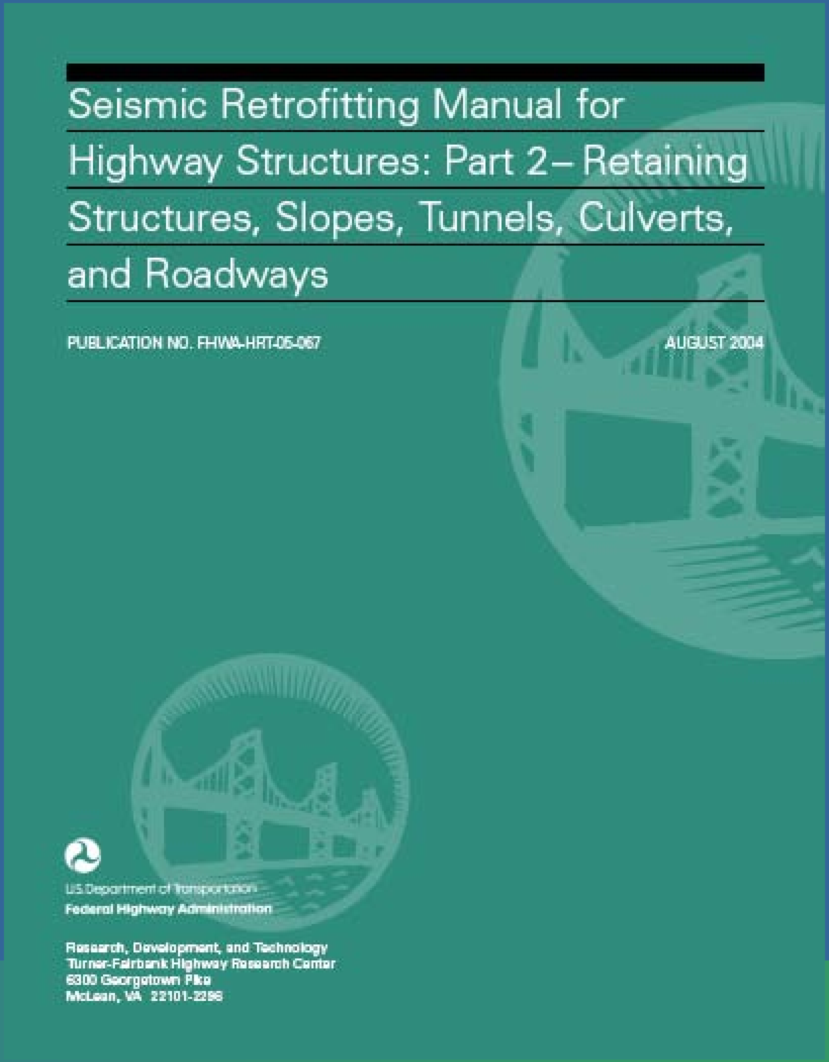


Seismic Retrofitting Manual for Highway Structures: Part 1 – Bridges

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

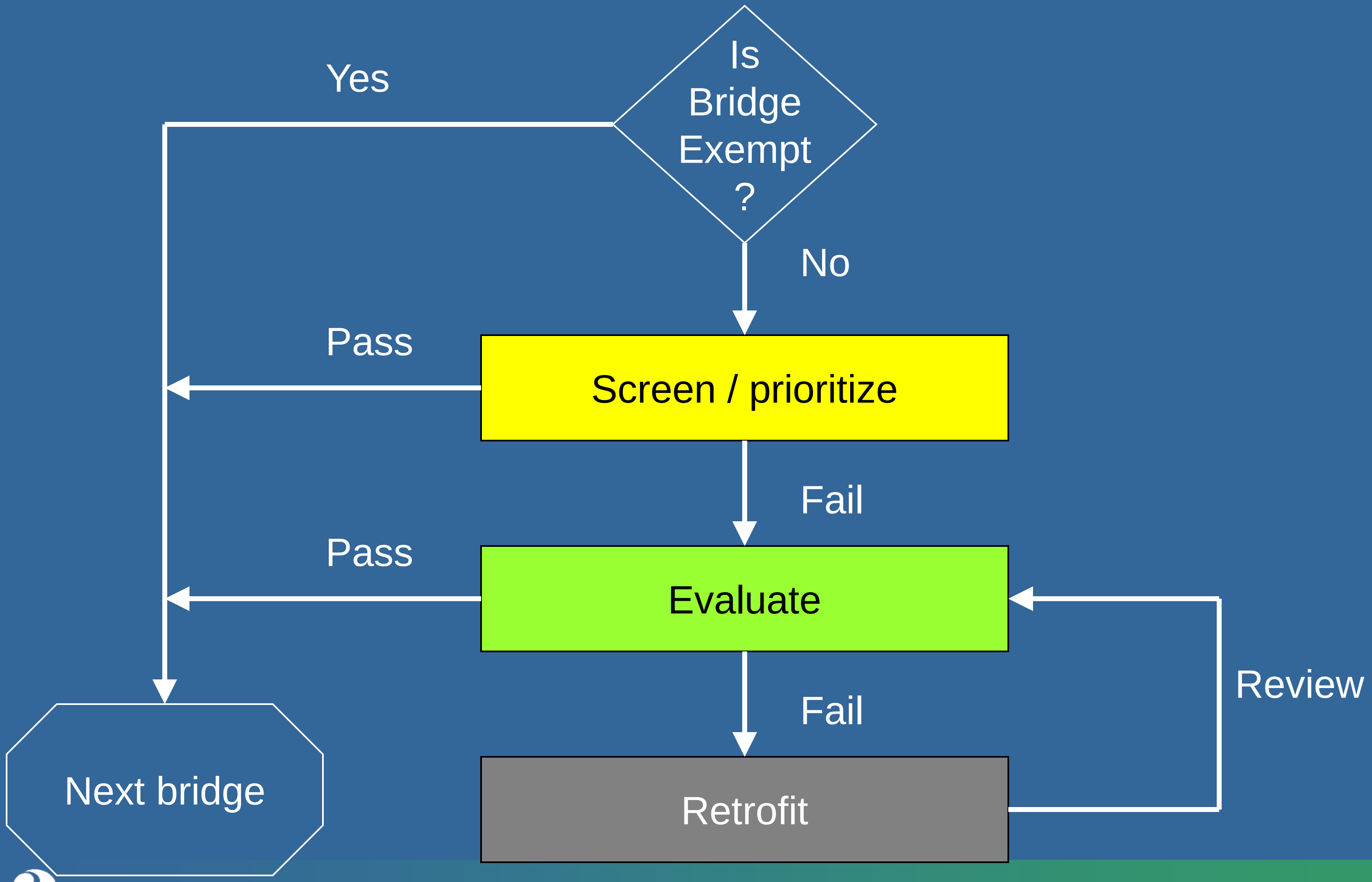


Seismic Retrofitting Manual for Highway Structures: Part 2 – Retaining Structures, Slopes, Tunnels, Culverts, and Roadways

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


Is
Bridge
Exempt
?
Yes
No
Screen / prioritize
Pass
Fail
Evaluate
Pass
Fail
Retrofit
Review
Next bridge

Performance-based retrofit

- Explicit attempt to satisfy public expectations of bridge performance for earthquakes ranging from small to large… for example:

Performance	Earthquake		
	Small	Intermediate	Large
No interruption	√	√	
Limited access		√	√
Closed for repairs			√

Performance-based retrofit

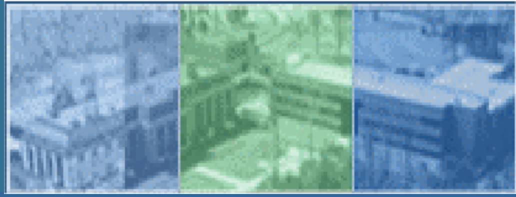
- Application of *performance-based design* to bridge retrofitting
  - two earthquake levels (Lower Level, Upper Level)
  - two bridge types (standard, essential)
  - three service life categories (ASL1,-2,-3)
  - two performance levels (life safety, operational)

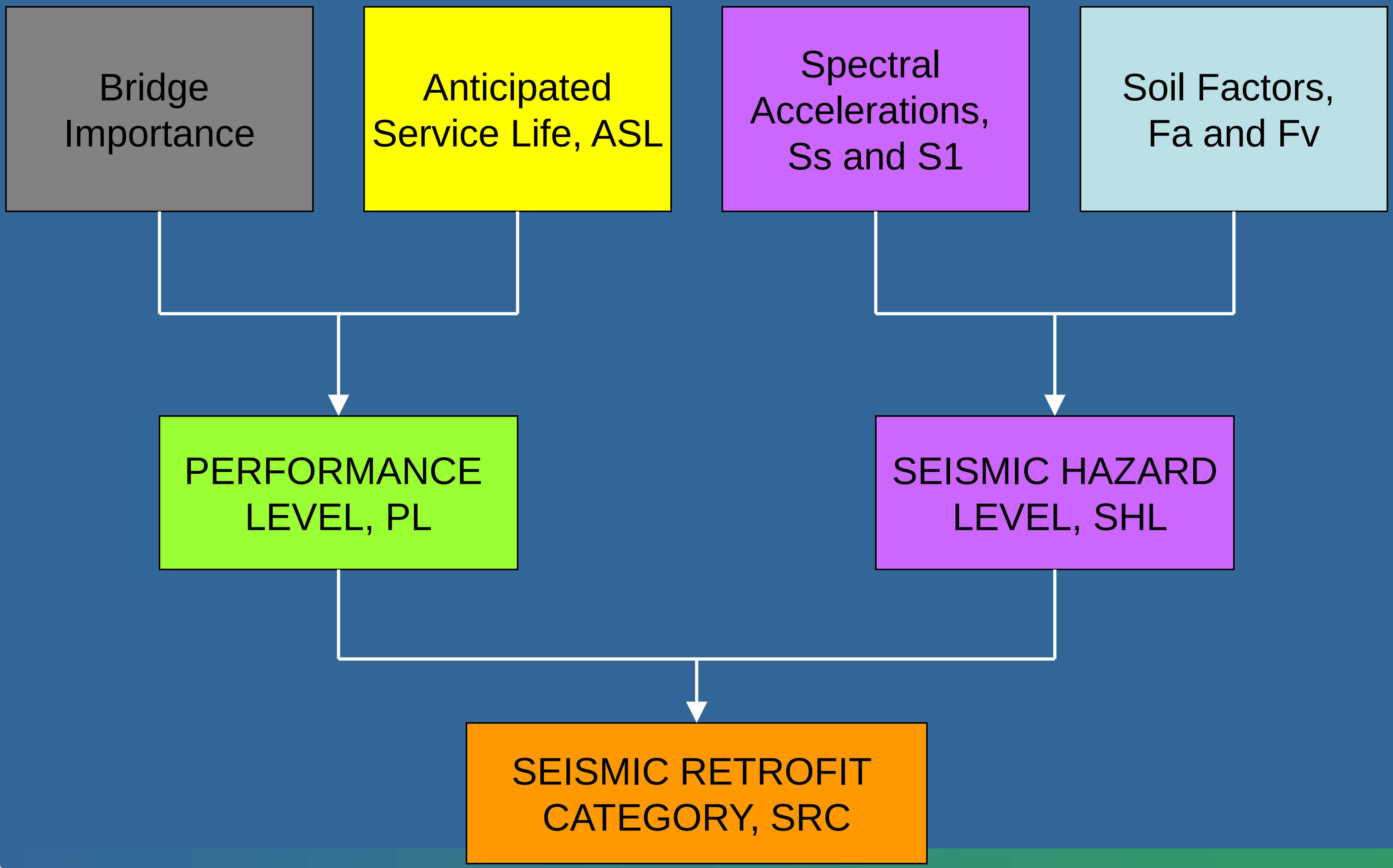
Seismic retrofit categories

- *Seismic Retrofit Categories*, *SRC*, are used to recommend minimum levels of
  - screening
  - evaluation, and
  - retrofitting

  If these minima are satisfied, the required performance levels will be satisfied.

- SRCs are similar to *Seismic Performance Categories (SPC)* used in new design



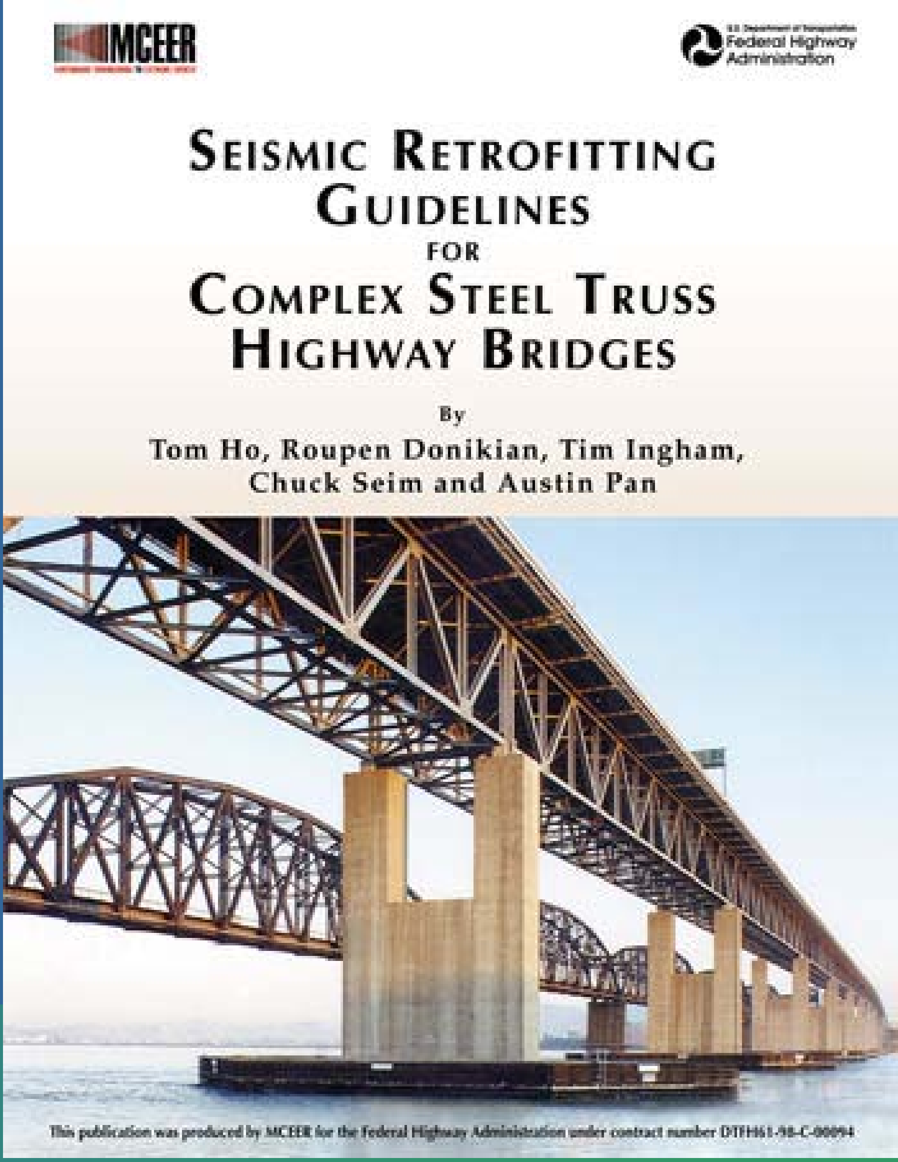

Bridge Importance
Anticipated Service Life, ASL
Spectral Accelerations, Ss and S1
Soil Factors, Fa and Fv
PERFORMANCE LEVEL, PL
SEISMIC HAZARD LEVEL, SHL
SEISMIC RETROFIT CATEGORY, SRC

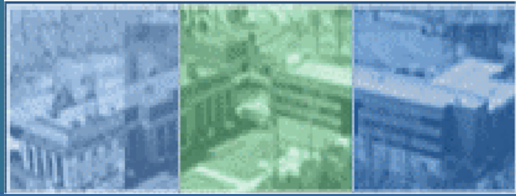
Upper and lower level earthquakes

- Lower Level earthquake (LL):
  100-year return period
  (50% probability of exceedance in 75 years)
- Upper Level earthquake (UL):
  1000-year return period
  (7% probability of exceedance in 75 years)

Seismic Retrofitting Guidelines for Complex Steel Truss Highway Bridges

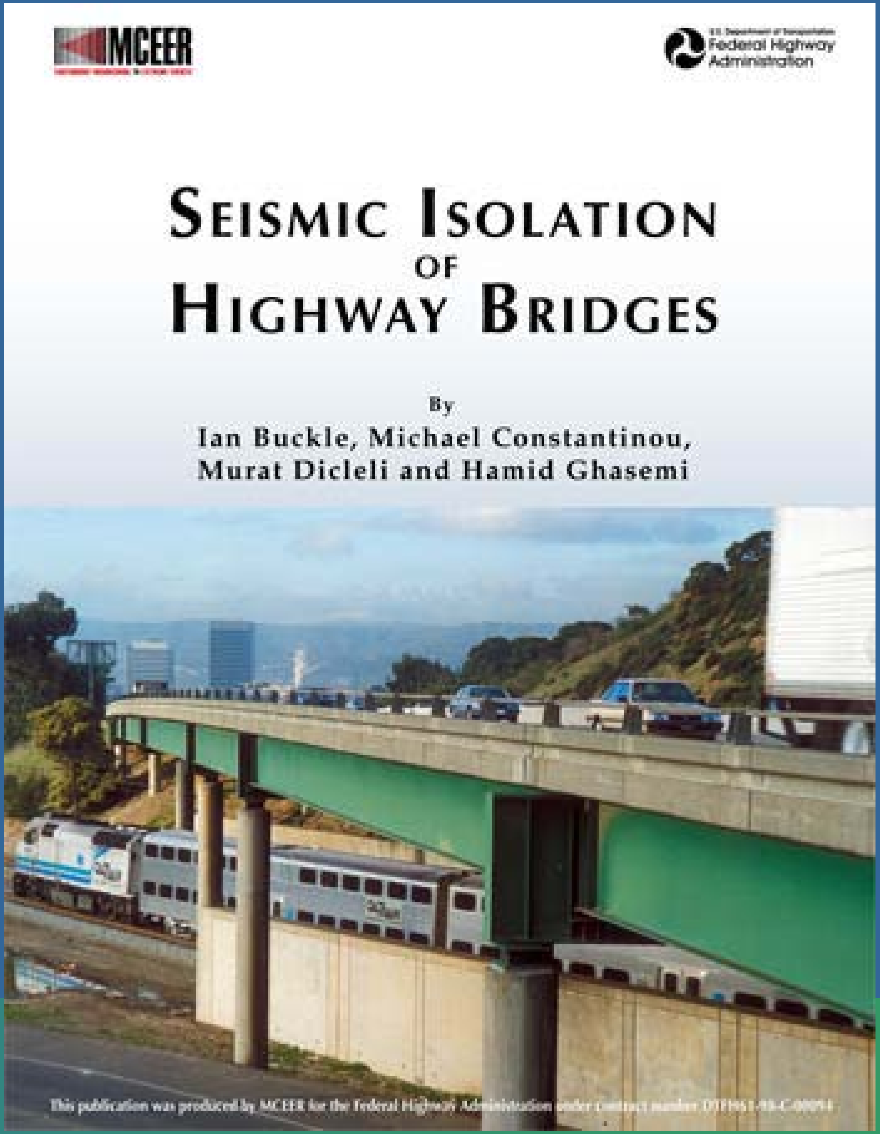
- T. Ho, R. Donikian, T. Ingham, C. Seim and A. Pan
- A performance-based seismic retrofit philosophy is used. The guidelines cover all major aspects pertinent to the seismic retrofitting of steel truss bridges, with a focus on superstructure retrofit. Case studies are provided.
  These guidelines are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





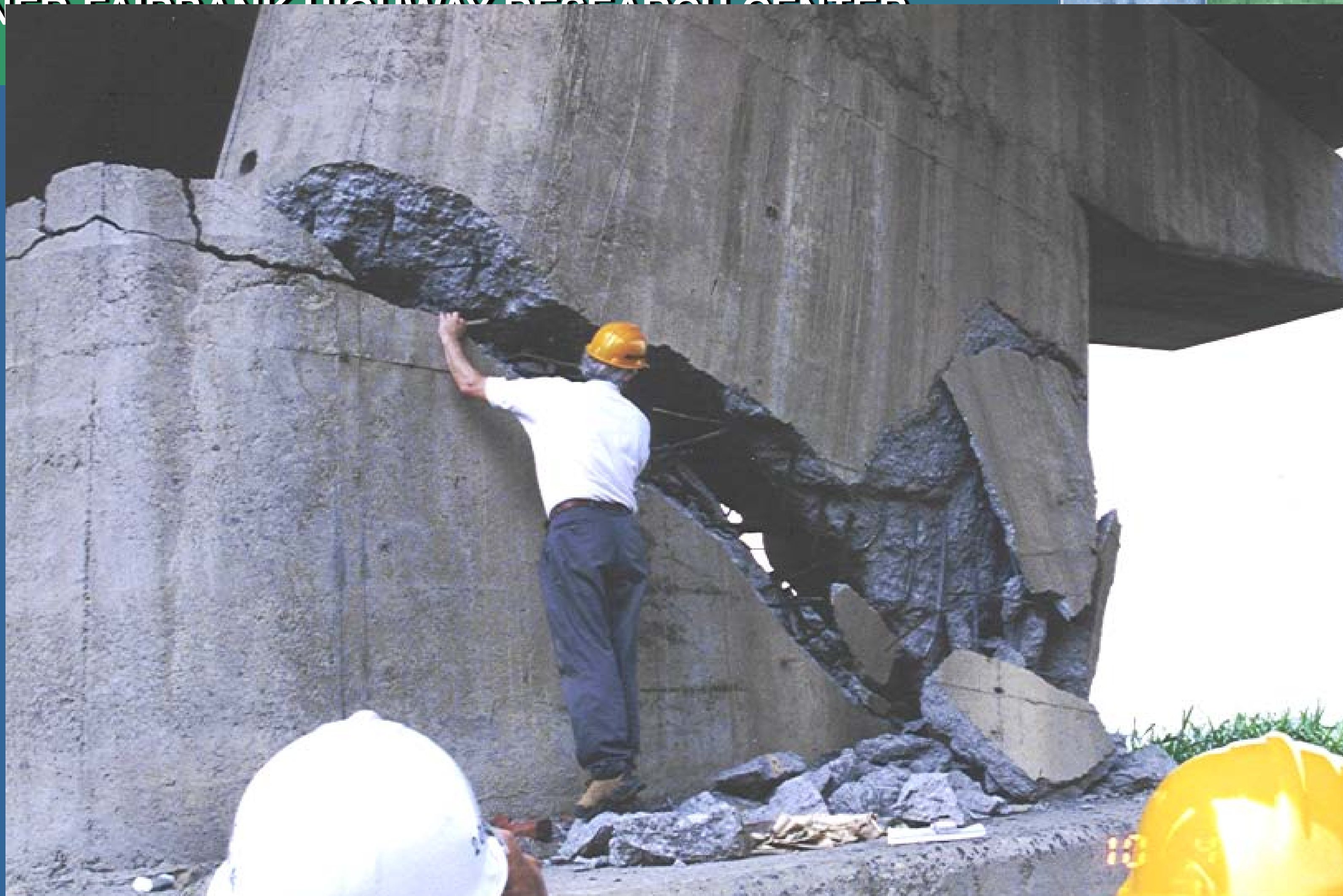
Seismic Isolation of Highway Bridges

- 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.



Mitigation Seismic Hazard through Reconnaissance

1995 Kobe Earthquake



Shear failure in pier of Wu-shi bridge, Chi-chi Earthquake, Taiwan, September 1999

Failure of shear-critical columns in Tong-tou bridge, Chi-chi Earthquake, Taiwan, September 1999

一、桥梁震害：

图 1 庙子坪大桥引桥落梁

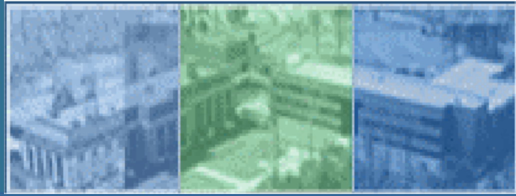
LESSONS LEARNED SINCE SAN FERNANDO

- New Design Perform Well
- Retrofit Works

Mitigation Seismic Hazard through Advanced Research

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

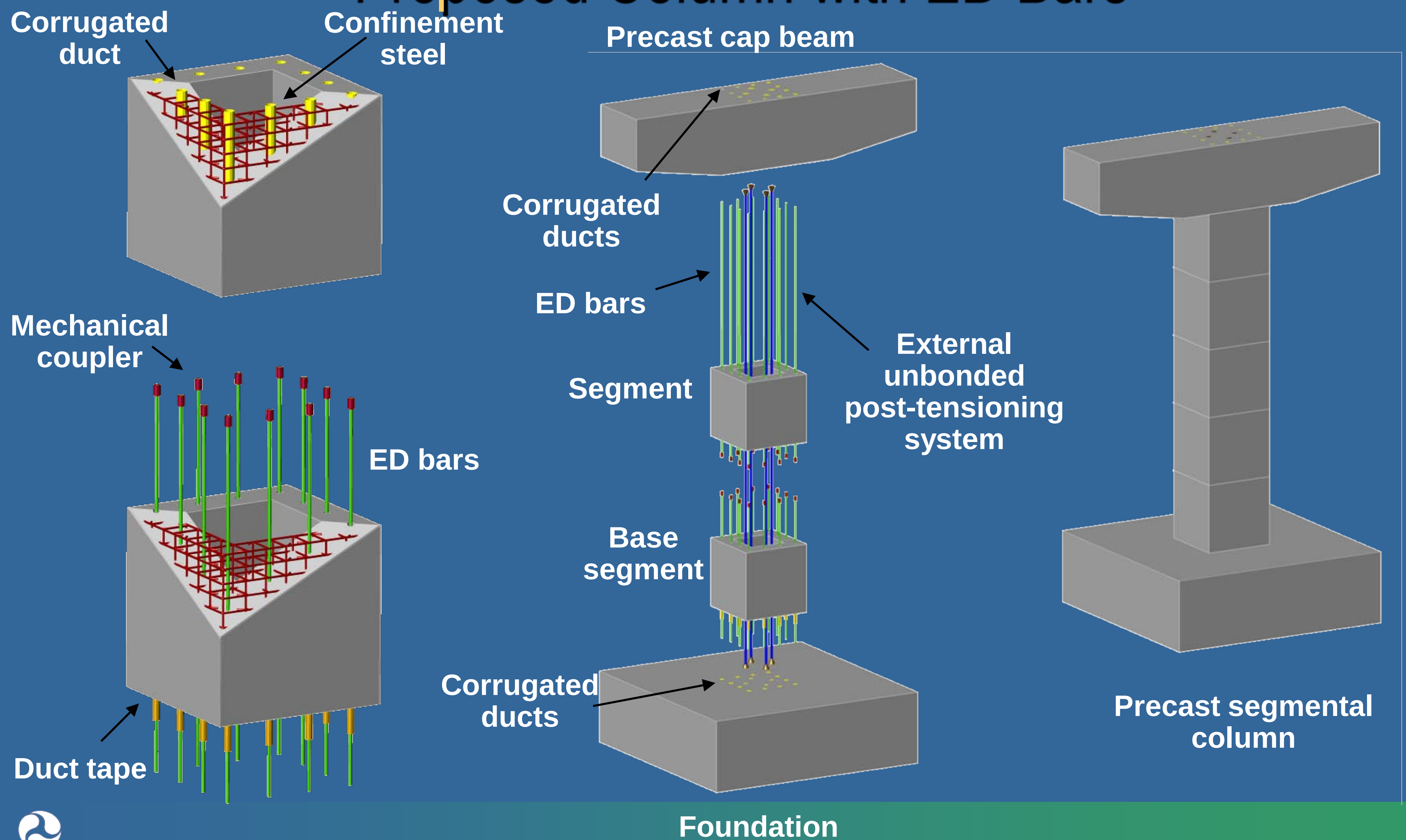
- For MCEER (Buffalo)- $4.0 M Advancing Seismic Design and Construction Technology for Highway System
- For UNR (RENO) – $4.0 M Developing Integrated System for Seismic Risk Assessment
- For MCEER (Buffalo) – $3.0M Developing Multiple Hazard Design Principle for Highway Bridges



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..

Proposed Column with ED Bars

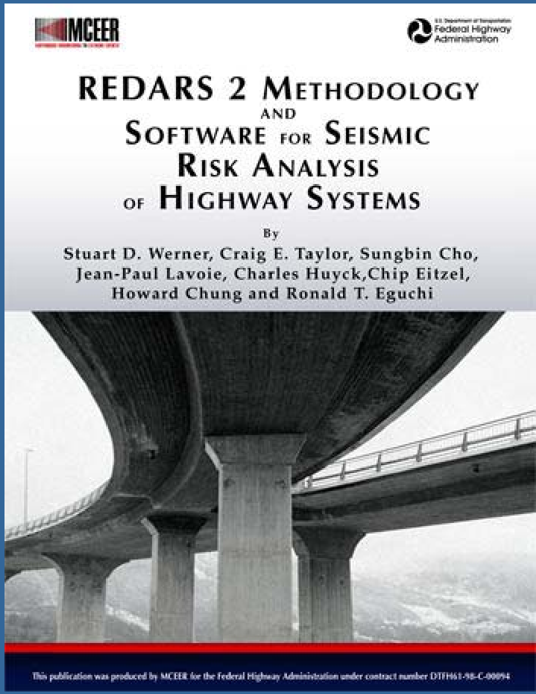


SAFETEA-LU

- 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

Full Scale Seismic Performance Testing of Bridge Column

- Objectives

- Provide Good Test Data Which Are Useful to Solve "Scale Effects," and Calibrate Analytical Models
- Verification of Small & Medium Scale Test Results
- Educational Purpose to Public

National Cooperative Projects - Pooled Fund Study

- Full-Scale Bridge Column Model Shake-Table Tests
  - A National Cooperative Research
  - A Bench Mark Test for Bridge Model W/O Scaling Effects
  - Tested in 09/2010 (UCSD Shake table)
  - Funding Committed: NSF ($200K), FHWA thru MCEER & UNR ($200K), CALTRANS ($300K), MTDOT ($40K) – Total $740K

Transportation Seismic Activities in the Mid-America Region

- Research Studies
- Bridge Retrofitting

FHWA/ MST (Missouri Science and Technology) Seismic Study – $800K

- Earthquake Hazards Assessment and Mitigation: a Pilot Study in the New Madrid Seismic Zone
- Focused on Design, Retrofitting & Assessment of Highway Infrastructure
- Completed in year 2005

Seismic Retrofitting of Existing Transportation Infrastructures

- Through current Federal-Aid Program
- Bridge Seismic Retrofitting is eligible for these funding.

Seismic Retrofit of U.S. 40/I-64 Double Deck Bridge in Missouri

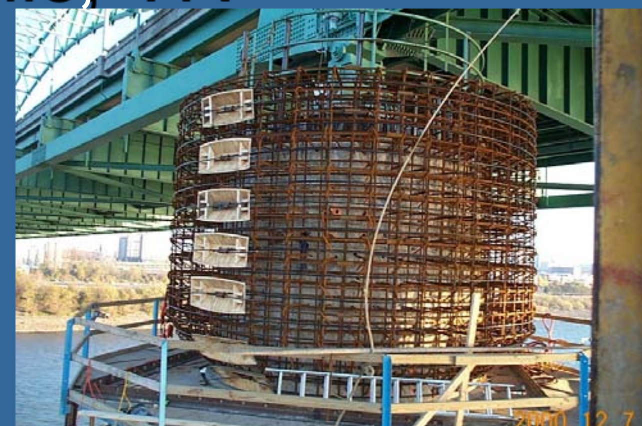
Seismic Retrofit of U.S. 40/I-64 Double Deck

Seismic Retrofit of I-40 Tie Arch Bridge in Memphis, TN

Seismic Retrofit of I-40 Tie Arch Bridge in Memphis, TN

Existing Bearing at Pier B

Seismic Retrofit of I-40 Tie Arch Bridge in Memphis, TN

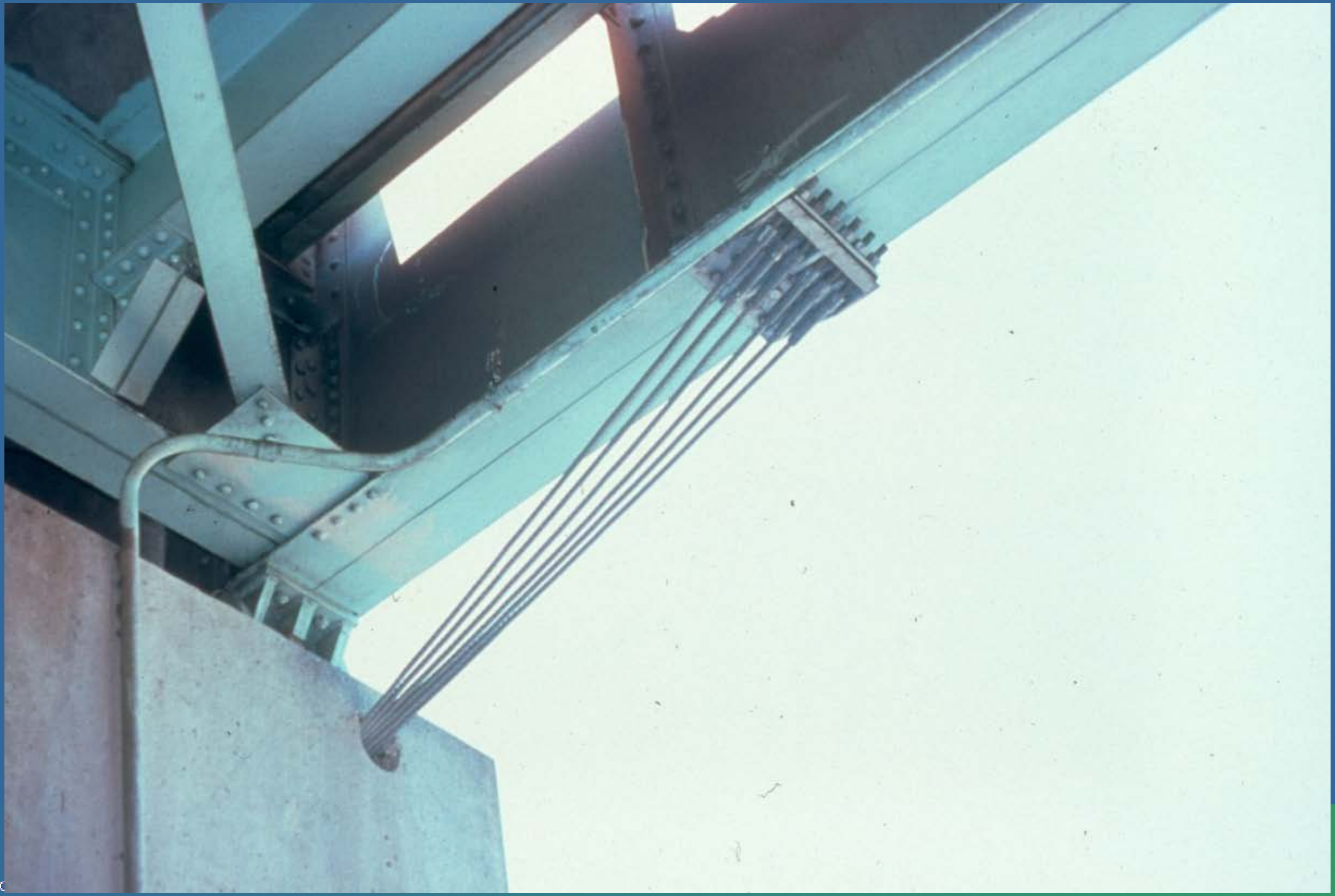


Pier B Bearing Replacement

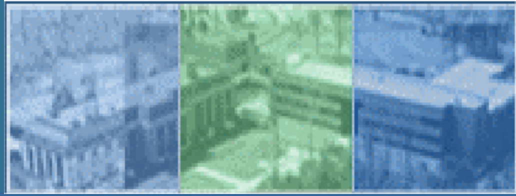
Multi-cable restrainer assembly

Precast girder anchorage

Steel girder anchorage



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER



Briefing on Impact of New Seismic Design Provisions on Bridges in Mid-America Research

TPF-5(155) FHWA, GA, IL, IN, MO, MS, TN

Reginald Desroches, Amr, Elnashai, Jamie Pagett, Jerry Shen, Linda Kuo, Phillip Yen

Objectives

To apply a comprehensive methodology to design bridges in the CSUS - using the NCHRP 12-49 as a basis (New Design Provisions 20-7 / 193). The methodology would address:

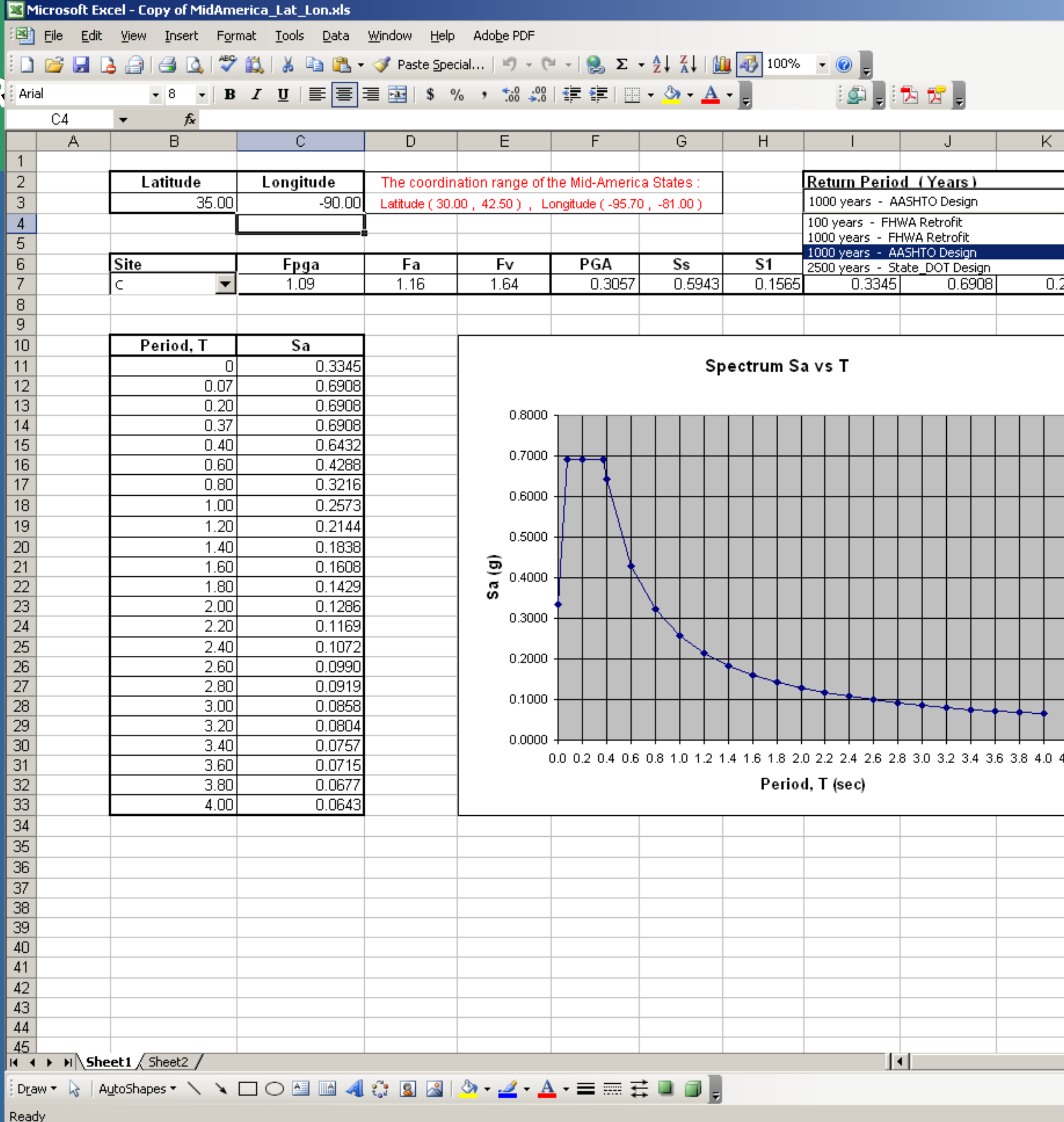
- Current source models and maps used for ground motion in the CSUS
- Current site response models
- Fragility models and network assessment to determine required level of seismic protection
- Detailed analysis to derive retrofit design forces and deformations

Work Performed

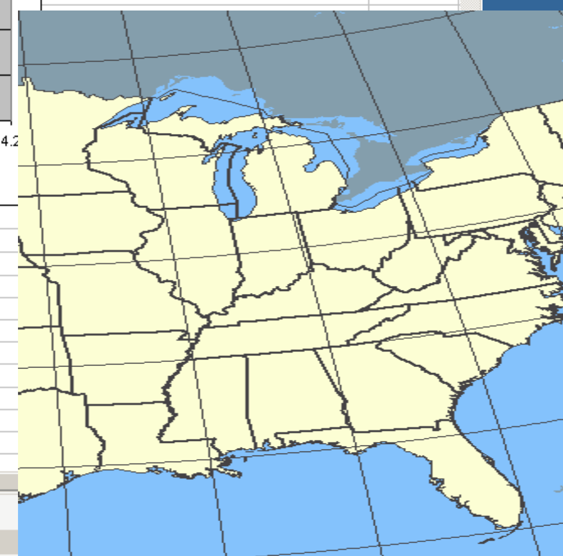
- Reviewed earthquake design values and procedures that produced these values in the CSUS area.
- Reviewed available tools for design seismic hazard determination, including those published by AASHTO and USGS.
- Obtained seismic hazard intensity grid data of the CSUS area.
- Produced ground motion computer software for use in design and retrofitting of bridges in the CSUS area.
- Review of literature to identify soil properties.
- Set up analytical framework for quantifying the effect of inelastic response of the soil on damage assessment of RC bridges.
- Set up analytical model for RC bridge.
- Set up soil model for the bridge.

Work Performed (cont.)

- Conducted a review of state seismic retrofit practices for states in Central and Southeastern US.
- Conducted a review of the state of seismic retrofitting practice in the CSUS. Documented theory, retrofitting details, and applications of various retrofits.
- Reviewed the LRFD Guidelines for Seismic Design of HW Bridges, NCHRP Project 20-07/ 193.
- Documentation of fragility analysis for Mid-America as-built and retrofitted bridges.
  - Preliminary analysis of bridge model with and without SSI
  - Preliminary analysis of bridge model with and without liquefaction
  - Spot analyses with model parameter variations
- Compared the different methods of analysis, from the elastic static response to the fully inelastic dynamic response analysis. Two bridge models, one simple and one complex multi-span structures, have been selected and modeled for the comparison study.



Period, T	Sa
0	0.3345
0.07	0.6908
0.20	0.6908
0.37	0.6908
0.40	0.6432
0.60	0.4288
0.80	0.3216
1.00	0.2573
1.20	0.2144
1.40	0.1838
1.60	0.1608
1.80	0.1429
2.00	0.1286
2.20	0.1169
2.40	0.1072
2.60	0.0990
2.80	0.0919
3.00	0.0858
3.20	0.0804
3.40	0.0757
3.60	0.0715
3.80	0.0677
4.00	0.0643



Spreadsheet tool to obtain ground motion parameters for design and retrofitting

U.S. Department of Transportation
Federal Highway Administration

Summary

- Background
  - Earthquake Hazard & Highway Infrastructure
  - FHWA Research Program
- Planning
  - REDARS Program
- Designing
  - New Design Spec
- Retrofitting
  - New Retrofitting Manuals

Thank you!

Questions?

For further information, please contact Dr. W. Phillip Yen at
Wen-huei.Yen@fhwa.dot.gov