# The Challenges of Transportation Infrastructure from Natural Hazards

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## Outline

- Where have we been
  - Lessons Learned
- Where are we
  - Risk Management & Hazard Mitigation
  - Retrofitting, Designing, Planning
- Where are we heading to & challenges
  - Advanced Research & International Cooperation
  - Challenges
- Concluding Thoughts

- **Where are we**
  - Risk Management & Hazard Mitigation
  - Using Earthquake as a case - Retrofitting, Designing, Planning

## RISK MANAGEMENT

- Managing uncertainties and harmful consequences associated with a hazard.

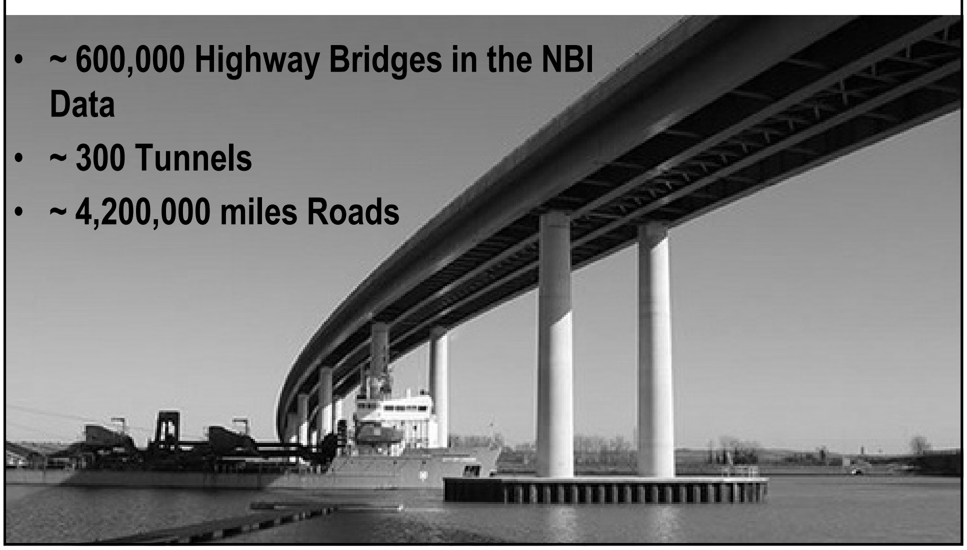
- Hazard: Likelihood of occurrence of a natural event in terms of it’s maximum intensity
- Vulnerability: Weakness or fragility of roads/bridges against a natural event
- Risk : Quantitative expression of uncertainties and harmful consequences associated with a hazard

## Tasks of RISK MANAGEMENT

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

## US Highway Infrastructure Inventories

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



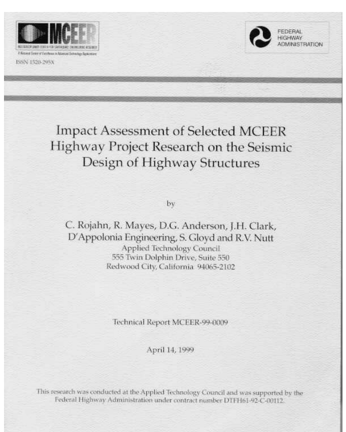
## Significant Earthquake Damages in the U.S. 1964-2001

| 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?** |

## 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

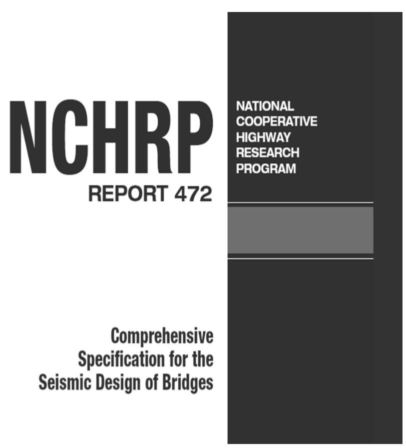
by

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

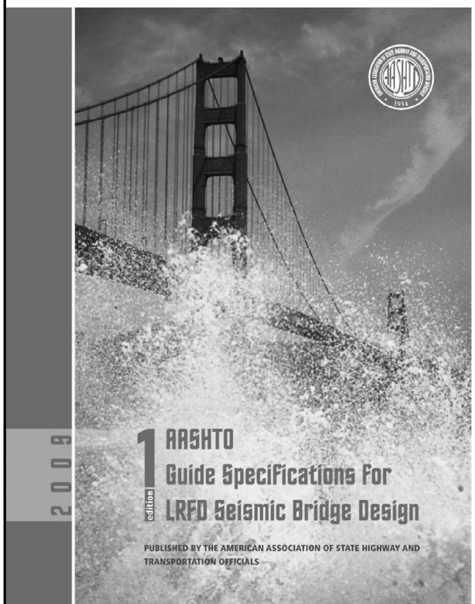
This research was conducted at the Applied Technology Council and was supported by the Federal Highway Administration under contract number DTFH61-92-C-00112.



NCHRP
REPORT 472

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Comprehensive Specification for the Seismic Design of Bridges




**ABBREVIATED TABLE OF CONTENTS**



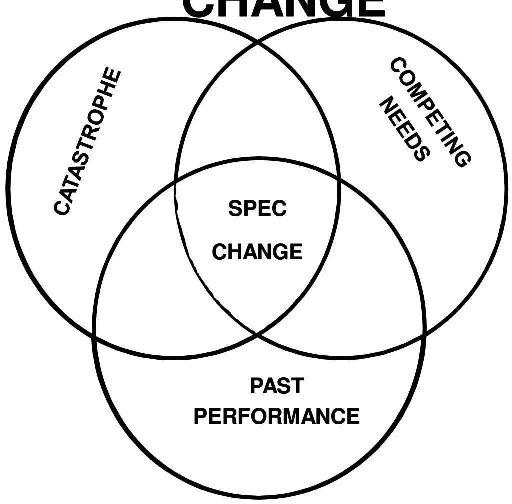
# PERFORMANCE CRITERIA

- 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.**

## IMPLEMENTING SPECIFICATION CHANGE

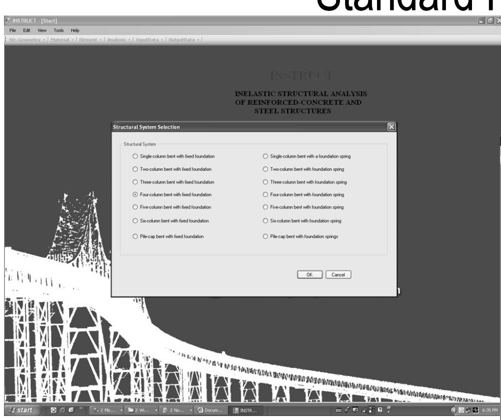


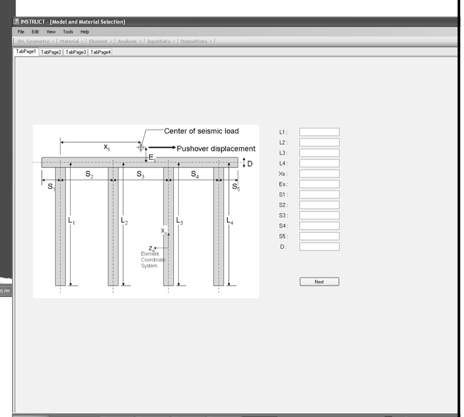
## INSTRUCT Pushover Analysis Program

OBJECTIVE

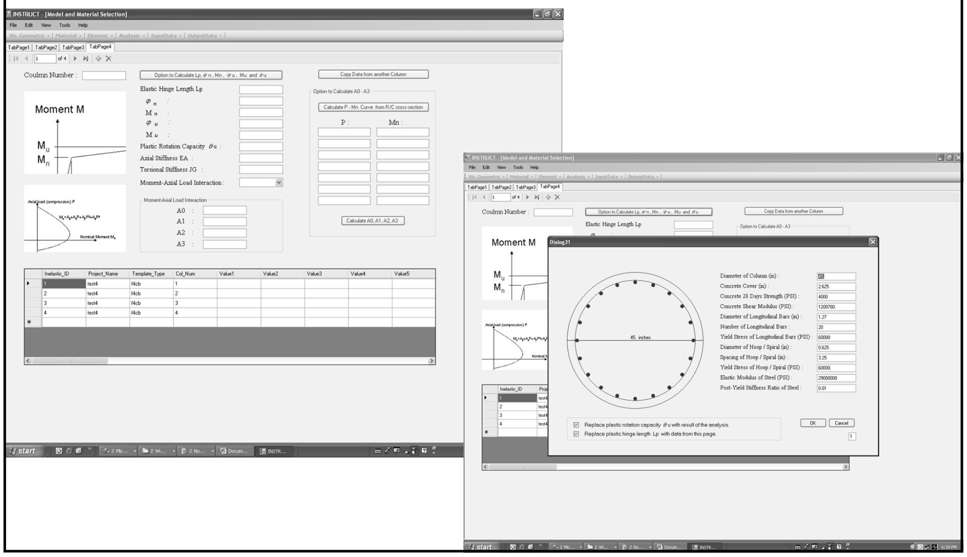
- **This project aims to develop a window-based user-friendly interface for the current developed inelastic structural pushover analysis FORTRAN computer program. The ultimate goal is to provide State DOTs a useful tool (not a mandated tool) for the pushover analysis of highway bridges.**

## Standard Program



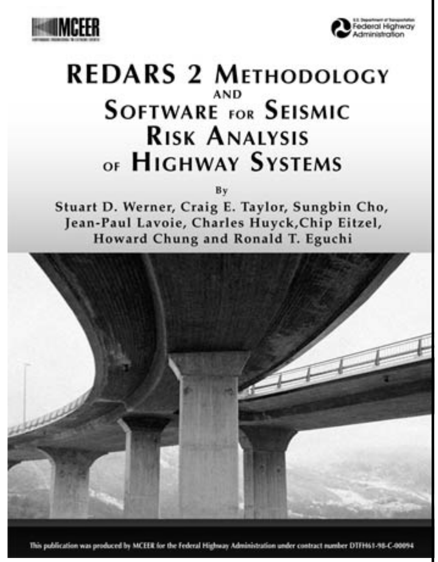
## Standard Program




## Mitigation Seismic Hazard through Planning

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

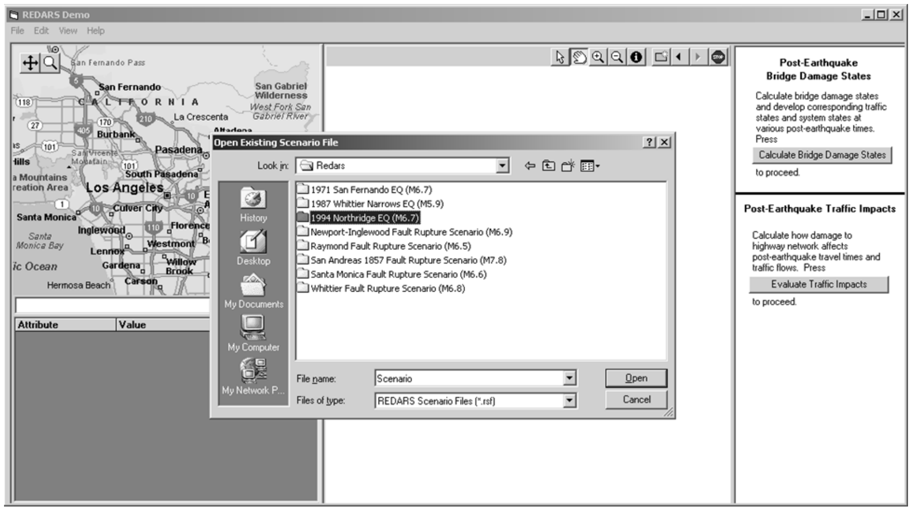
- S.D. Werner, C.E. Taylor, S. Cho, J-P. Lavoie, C. Huyck,
  C. Eitzel, H. Chung and R.T. Eguchi
- **The REDARS 2 report provides the basic framework and a demonstration application of the Seismic Risk Analysis (SRA) methodology and its modules. The main modules of the REDARS 2 SRA methodology include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



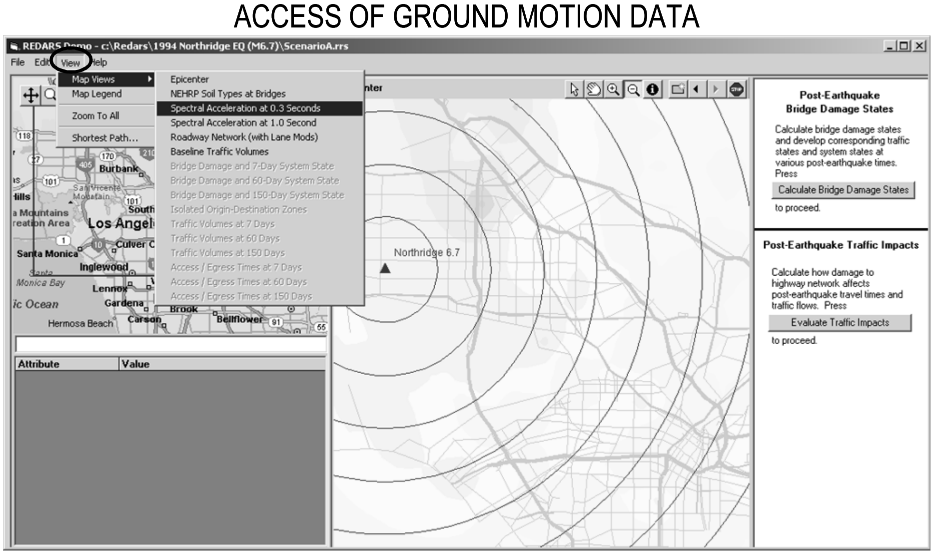

REDARS SOFTWARE:
DESCRIPTION

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

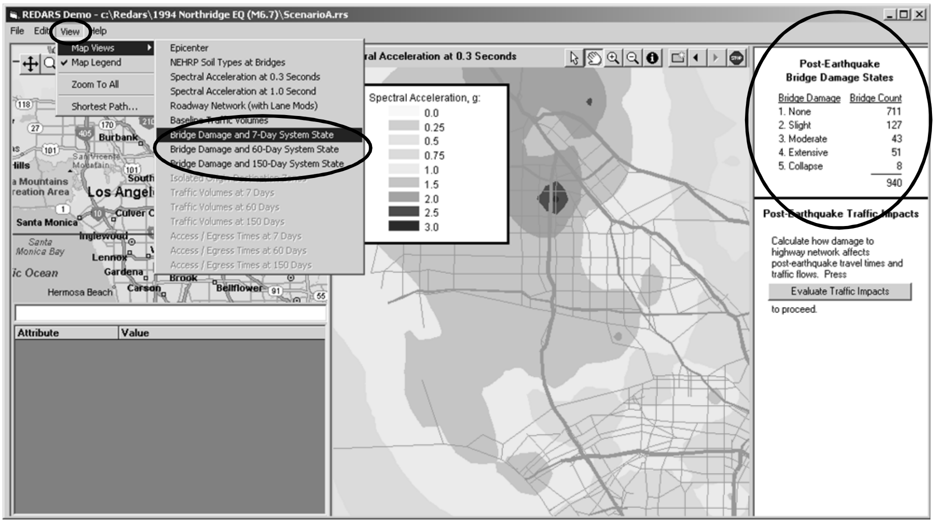
DIALOGUE BOX TO SELECT NORTHRIDGE EQ



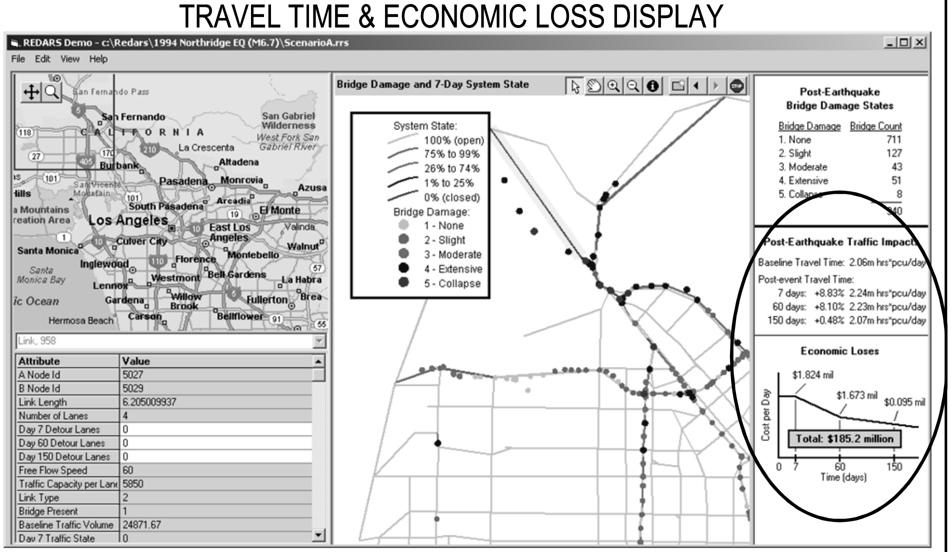

DROP-DOWN MENU:
ACCESS OF GROUND MOTION DATA



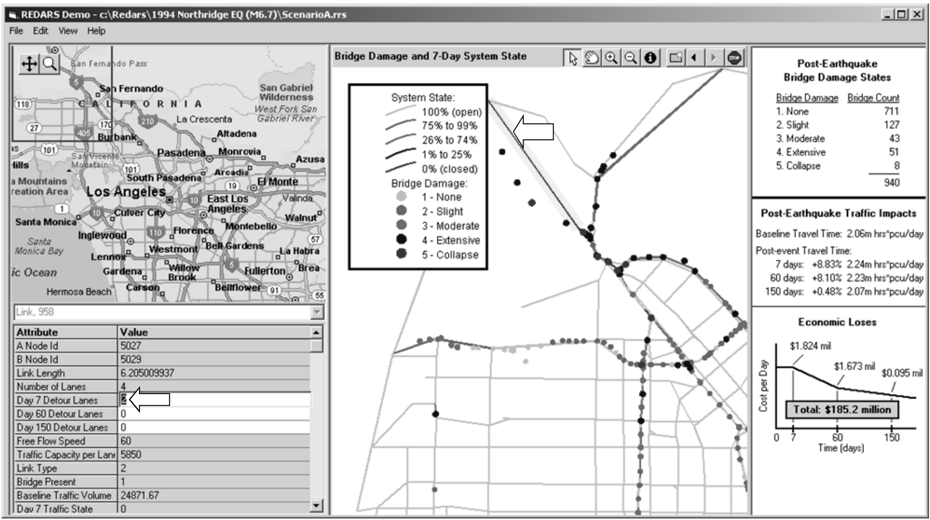
## DROP-DOWN MENU: ACCESS BRIDGE DAMAGE & SYSTEM STATE DISPLAYS




## AFTER NETWORK ANALYSIS: TRAVEL TIME & ECONOMIC LOSS DISPLAY

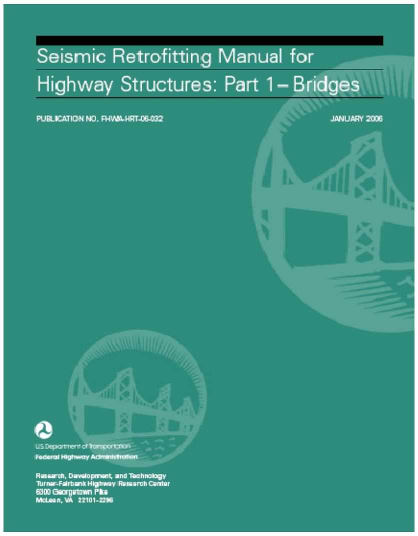


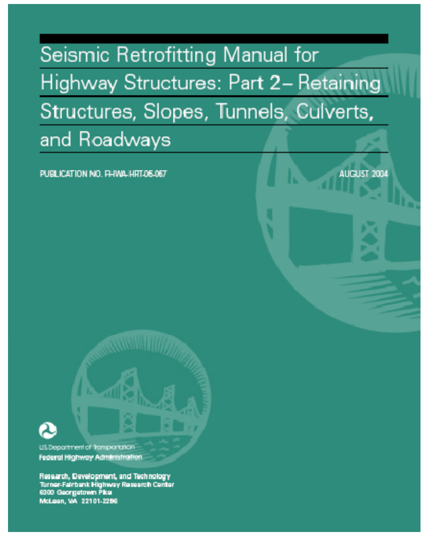
REAL-TIME ASSESSMENT OF ALTERNATIVE EMERGENCY RESPONSE STRATEGIES: (ADD DETOUR LINK ALONGSIDE DAMAGED BRIDGE)




Mitigation Seismic Hazard through Retrofitting

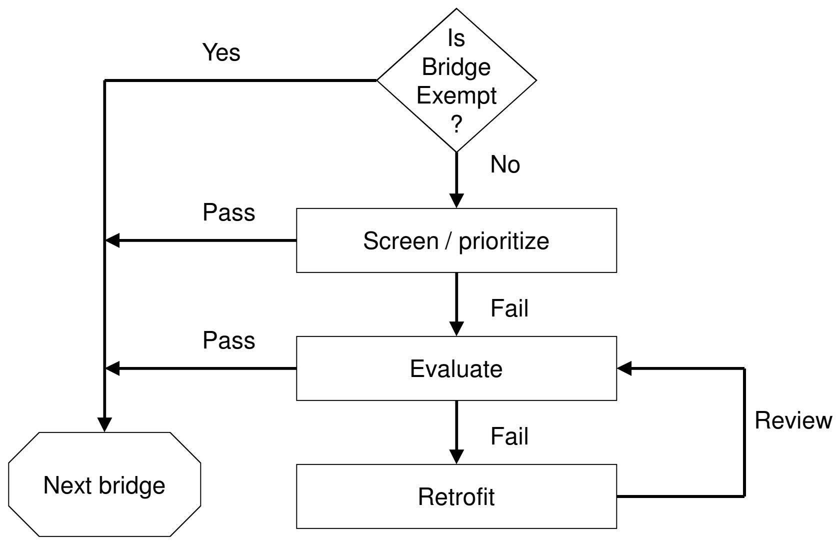
## NEW FHWA Seismic Retrofitting Manuals



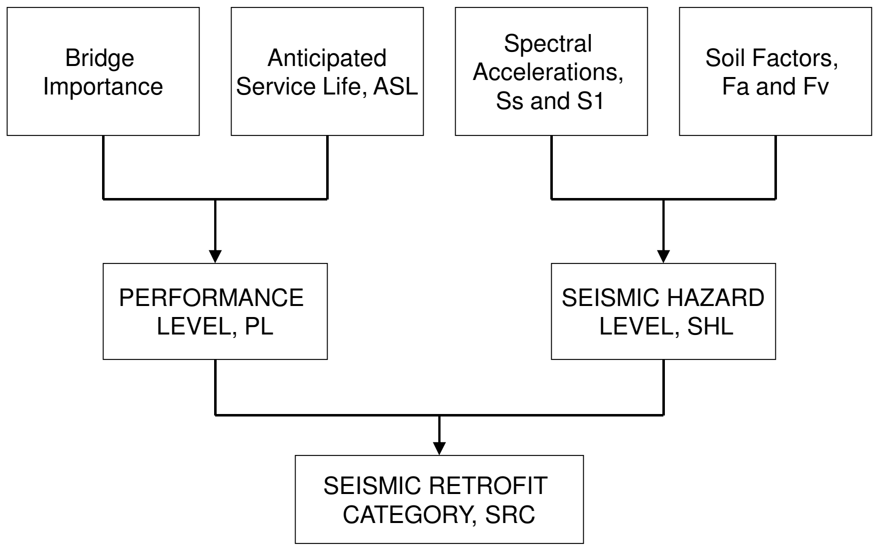

## Content

- **Philosophy and process**
- **Screening a bridge inventory**
- **Evaluation of bridge performance**
- **Retrofit strategies for deficient bridges**




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)**

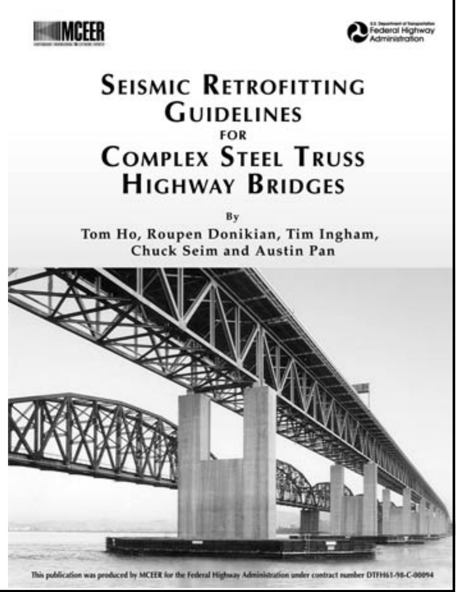



## Upper and lower level earthquakes

- **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)**

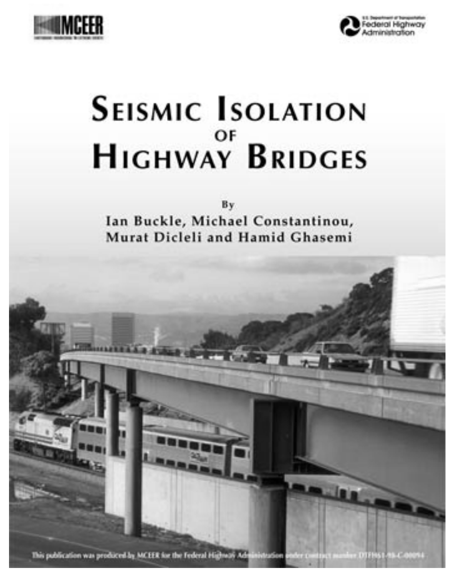
## Seismic Retrofitting Guidelines for Complex Steel Truss Highway Bridges

- 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

**LESSONS LEARNED SINCE SAN FERNANDO**

- **New Design Perform Well**
- **Retrofit Works**



- **Where are we heading to & challenges**
  - **Advanced Research & International Cooperation**
  - **Challenges**

Advanced Research

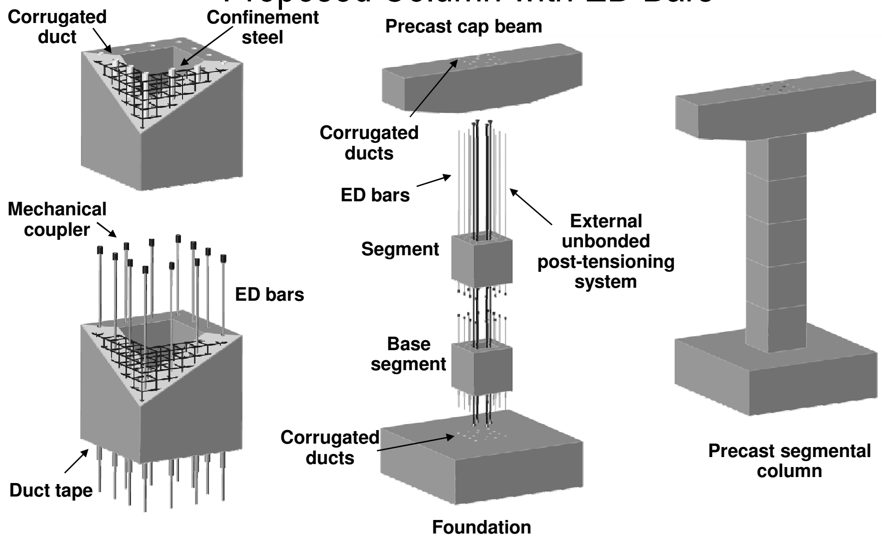
## SAFETEA-LU Seismic & Multi-hazards Research - 2005-2009

- **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

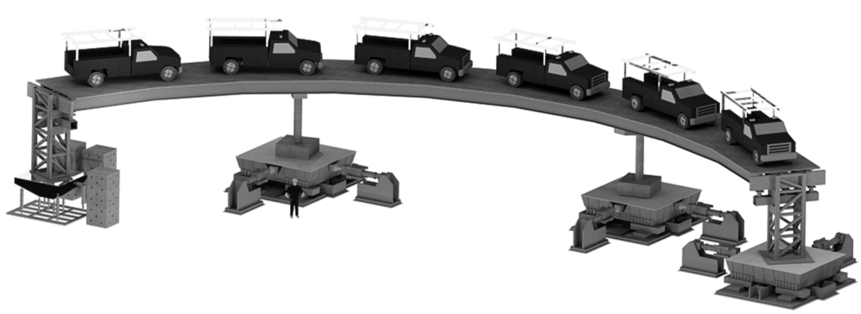



## Large Scale Segmental Bridge Test

# SAFETEA-LU

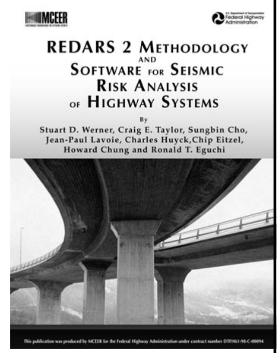
- **For UNR (RENO) - about $4.0M   Developing Integrated System for Seismic Risk Assessment**
  - ENHANCEMENTS TO LOSS-ESTIMATION TECHNOLOGIES FOR HIGHWAY SYSTEMS
    - **REDARS-2™ CUSTOMIZATION FOR RESILIENCE STUDIES**
    - **CHARACTERIZATIONS OF SEISMIC HAZARDS FOR NEAR-FAULT BRIDGES**
  - DESIGN 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

# LARGE SCALE HORIZONTALLY CURVED BRIDGE SEISMIC PERFORMANCE STUDY



## 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.**




## 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**

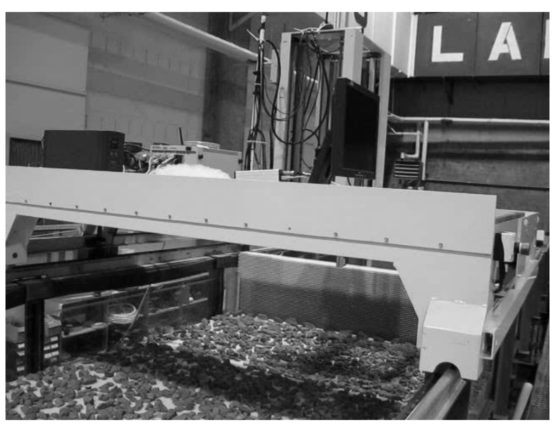
Physical Modeling Lab at TFHRC in McLean, VA

FHWA Hydraulics R&D Program

High Performance Computing Simulation Lab at DOE's Argonne National Laboratory, Argonne, IL

FHWA Hydraulics R&D Program

<u>Update scour prediction for course bed material</u>

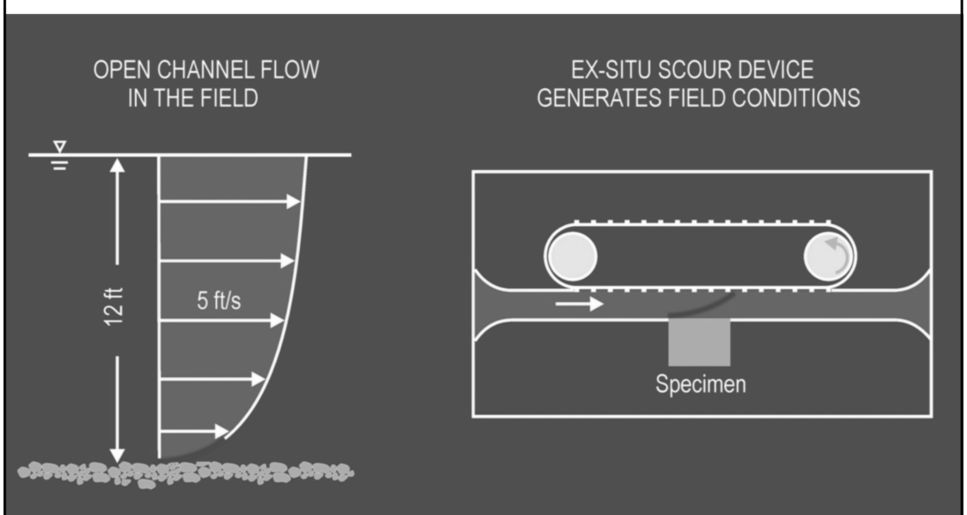


Research to develop new Design Guidance

## Scour in clay soils

Super Flood in West Tennessee in May 2010

Research to develop new Design Guidance

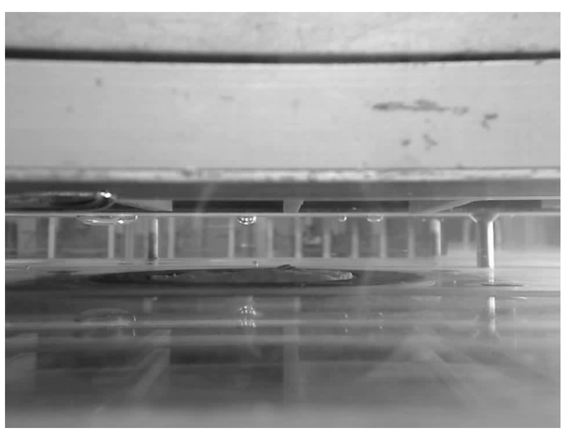



Research to develop new Design Guidance – Scour in clay soils

## Scour in clay soils/Ex-situ Scour Testing Device

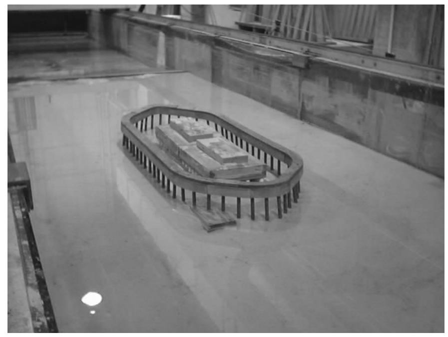
Research to develop new Design Guidance – Scour in clay soils

## Incipient motion of clay soils



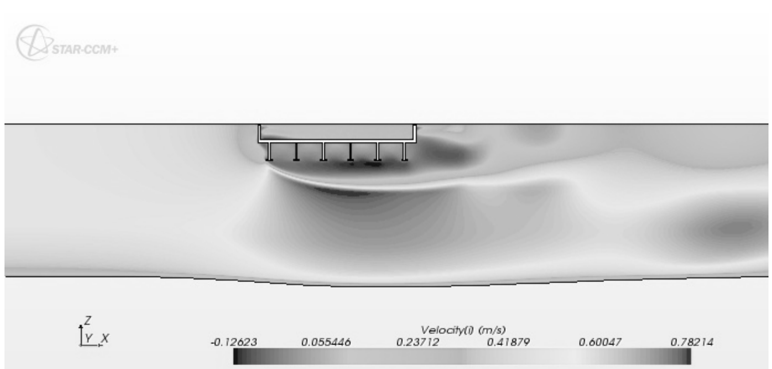
Research to develop new Design Guidance – Scour in clay soils

## Woodrow Wilson Bridge Study



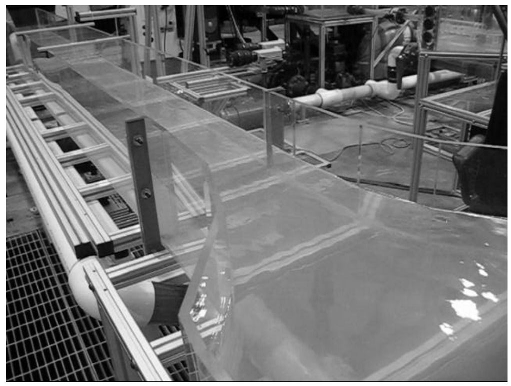
Partnerships with State DOT's

## Interagency Agreement with DOE/ANL for computer modeling and flow visualization (cont'd)




Partnerships with other Agencies

## Interagency Agreement with DOE/ANL for computer modeling and flow visualization (cont'd)



Partnerships with other Agencies

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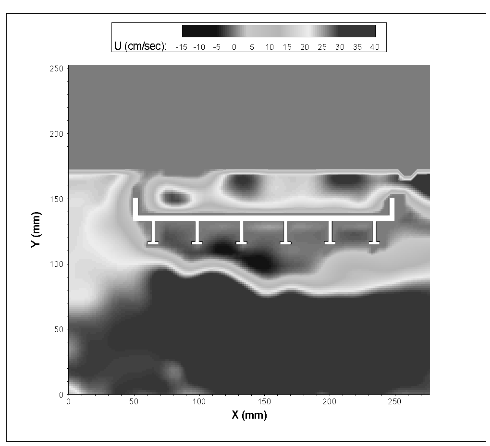
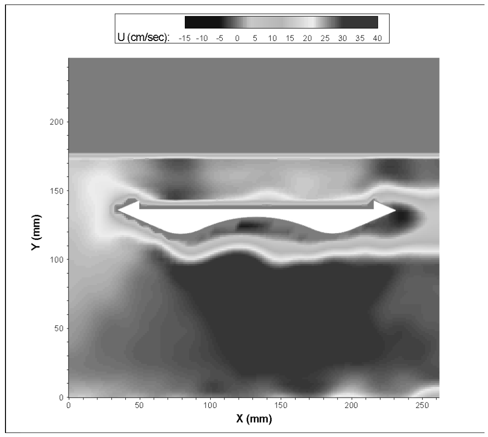


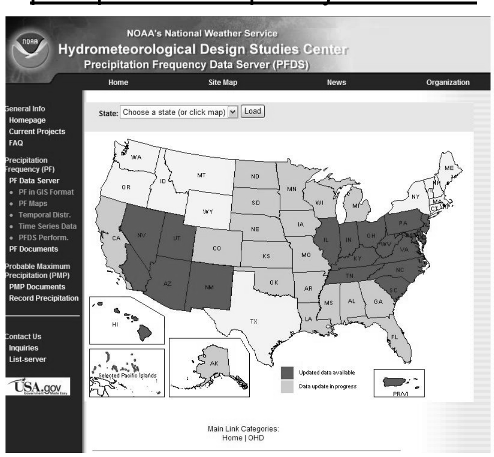

Partnerships with other Agencies

Interagency Agreement with DOE/ANL for computer modeling and flow visualization (cont'd)




Partnerships with other Agencies

Interagency Agreement with DOC/NOAA to update the precipitation frequency estimates



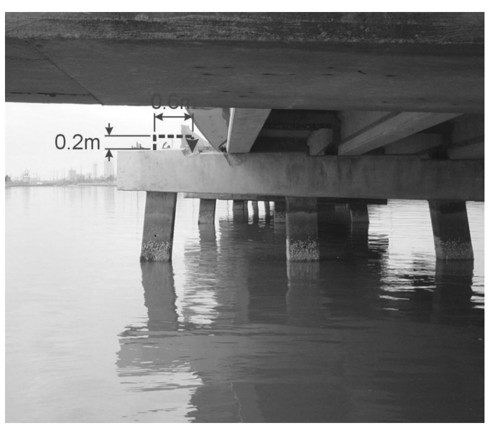

Partnerships with other Agencies

## Wave Forces on Bridge Decks – Hurricane Katrina 2005

US 90 Ocean Springs, LA

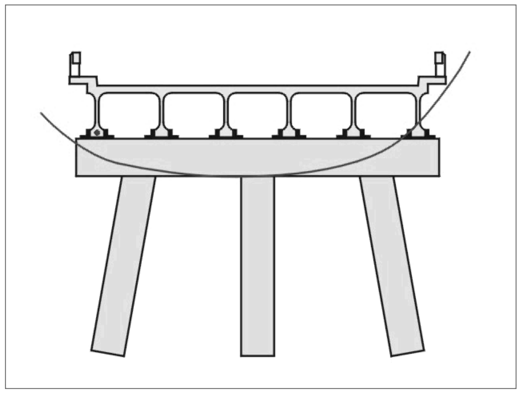
Forensic analysis of bridge failures

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




Forensic analysis of bridge failures

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



Forensic analysis of bridge failures

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

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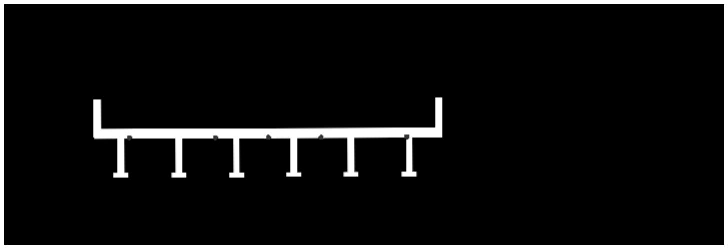
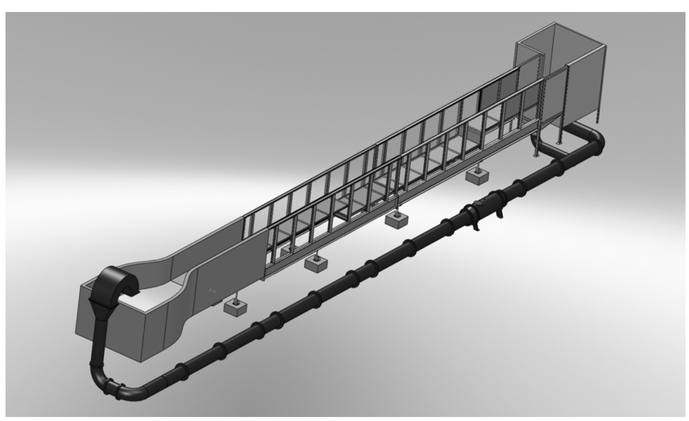


Forensic analysis of bridge failures

## New Sediment Recirculation Flume



Future Hydraulics R&D Work Plan

## New Sediment Recirculation Flume (cont'd)

Future Hydraulics R&D Work Plan

- **On November 7, 1940, the dramatic collapse of the Tacoma Narrows Bridge sparked renewed research into the aerodynamics of suspension bridges.**

## Recent and Ongoing Research on Wind Hazard

- **The FHWA Aerodynamics Laboratory recently conducted research on wind loading in five project areas:**
- **highway signs and lights,**
- **cable-supported structures,**
- **full-scale measurements,**
- **long-term monitoring,**
- **and large amplitude cable vibration.**

## New Research Activities

- ***Optimization of aerodynamic performance*. In the structural design of cable-stayed bridges, several road deck cross sections appear to have become favorites among design consultants throughout North America.**

- ***The Vibration of stay cables*** **- to address the problem of wind-induced large amplitude vibration of bridge stay cables**

## Multi-hazard Research

- **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**

## Research Needs on Seismic Performance Evaluation of Highway Bridges Subjected to Long Duration Earthquakes

## Advanced Researches Needed

It has been noted that the recently occurred devastating earthquakes over the world have a longer duration comparing with earlier earthquake records, e.g.,

- Tohoku Region Pacific Ocean Offshore Earthquake (Japan, 03-11-2011) --- 300 Sec.
- Maule Region Offshore Earthquake (Chile, 02-27-2010) – 200 Sec.
- Wenchuan Earthquake (China, 05-12-2008 ) – 180 Sec.

The long duration earthquakes may cause more severe damage to buildings and bridges, which may need to be studied and dealt with carefully in structural seismic performance evaluation and codes development.

- **BIG Challenges From Natural Hazards**
  - **Climate Changes**
  - **Global Warming**

# Challenges

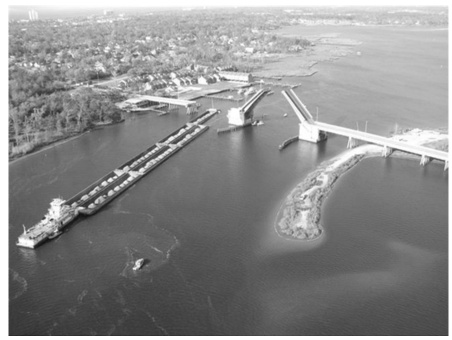
- **Earthquakes**
  - **Magnitudes > 8.0 , 9.0**
  - **Longer Durations > 3 minutes**
  - **Bridge Crossing Active Faults**
- **Floods/ Scour - Hydraulic Issues**
  - **Flow direction? Reflecting angles?**
  - **Bridge location –**
    - **should be built in the shortest span length?**
- **Hurricanes/ Typhoons**
  - **Combinations w/ Wave Force?**
  - **What is the flood height should be considered?**

# Forces of Nature - Floods

**Forces of Nature – Scour and Washout**

# Others - Human Factors


# Human Factors



# Human Factors

## Competing the needs

- **Budget Issues**
- **Prioritizations/ Time**
- **Performance Based Design/ Performance Measurements**

## Estimated Annualized Losses by Hazard

| **Hazard** | **Estimated Annualized Loss ($ billions)** |
|---|---|
| Hurricanes | 5.0 |
| Winter Storms | 0.3 |
| Tornadoes | 1.0 |
| Total Wind | 6.3 |
| Floods | 3.0 |
| Hail | 0.7 |
| Extreme Heat | 0.1 |
| Extreme Cold | 0.5 |
| Total All Weather | 10.6 |
| Wildfires | 2.0 |
| Earthquakes | 4.4 |

# Summary

- **Background**
  - **Natural Hazards & Transportation Infrastructure**
  - **FHWA Research Program**
- **Planning**
  - **REDARS Program**
- **Designing**
  - **New Design Spec**
- **Retrofitting**
  - **New Retrofitting Manuals**

Better Design Code = Better Performance

Well Preparedness = Reduce Loss

# Thank you!

# 谢谢！

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