REDARS 2 Software and Methodology for Evaluating Risks from Earthquake Damage to Roadway Systems

by

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<th>Role</th>
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</table>
ACKNOWLEDGEMENTS

• Project Sponsors (1993-2006)
  – Multidisciplinary Center for Earthquake Engineering Research (MCEER), Buffalo NY, and
  – Federal Highway Administration, Washington D.C

• REDARS Demonstration Project (2003-2006)
  – California Department of Transportation, Sacramento CA
PRESENTATION SCOPE

REDARS Methodology

• Future Directions
SEISMIC RISK ANALYSIS METHODOLOGY FOR HIGHWAY SYSTEMS

• Evaluate Ability of Highway System to Transport Traffic after EQ

• Estimate Losses from Damage to Highway System
  – Economic
  – Increased Travel Times to/from Key Locations
  – Emergency Response/Recovery Impacts

• For Different Risk Reduction Options
INITIALIZATION:
Input Data to REDARS

- Publicly Available Data
- Augmented Data
PUBLICLY AVAILABLE DATA: Import Wizard

- Publicly Available Databases Needed to Define:
  - Roadway Topology & Attributes
  - Bridge Locations & Attributes
  - O-D Zones & Trip Tables
  - NEHRP Site Soil Conditions
PUBLICLY AVAILABLE DATA: Import Wizard

- Publicly Available Databases Needed to Define:
  - Roadway Topology & Attributes
  - Bridge Locations & Attributes
  - O-D Zones & Trip Tables
  - NEHRP Site Soil Conditions

- Wizard Facilitates this Process:
  - Accesses Public Databases in Wizard
  - Guides User thru Input Data Development
  - Resolves Any Database Inconsistencies
  - Checks Network Model and O-D Zone Connectivity/Continuity
IMPORT WIZARD RESULTS: REDARS INPUT DATA

Consistent Network Topography and Attributes

Bridge Locations & NBI Attributes; NEHRP Site Classifications

O-D Zones and Pre-EQ Trip Tables (for Auto, Various Freight, etc.)
AUGMENTED DATA: Earthquake Walkthrough Table

- **Starting Point: Recognized EQ Models**
  - From USGS (Frankel et al., 2002)
  - From Regional Agencies (e.g., CGS, CERI, etc.)

- **Select Walkthrough Duration** (years)

- **Randomly Sample Above EQ Models**
  - Establish Number, Magnitude, and Location of EQ Occurrences during Each Year (0, 1, or more)

- **EQ Sources**
  - Known Active Faults
  - Random Areal Zones

<table>
<thead>
<tr>
<th>Year No.</th>
<th>$M_w$</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>124</td>
<td>6.5</td>
<td>Random Areal Source 127 $(\text{Lat}<em>{124}, \text{Long}</em>{124})$</td>
</tr>
<tr>
<td>628</td>
<td>5.2</td>
<td>Random Areal Source 51 $(\text{Lat}<em>{628}, \text{Long}</em>{628})$</td>
</tr>
<tr>
<td>1,280</td>
<td>6.8</td>
<td>Calaveras Fault (initial rupture location, rupture length and direction)</td>
</tr>
<tr>
<td>1,649</td>
<td>7.2</td>
<td>Hayward Fault (initial rupture location, rupture length and direction)</td>
</tr>
<tr>
<td>2,249</td>
<td>6.2</td>
<td>Random Areal Source 329 $(\text{Lat}<em>{2,249}, \text{Long}</em>{2,249})$</td>
</tr>
</tbody>
</table>
OTHER AUGMENTED DATA

- Liquefaction
- Components (Retrofits, Bridge Overpasses)
- Override of Default Component Models for any Component(s)
RISK-ANALYSIS METHODOLOGY

INITIALIZATION
(input data, model parameters)

SYSTEM ANALYSIS
(for $i^{th}$ Simulation)

INCREMENTATION
(to Next Simulation)

AGGREGATION
(of Results from all Simulations)

Next Simulation
TYPES OF ANALYSES

• Deterministic
  – For Single Earthquake and Single Set of Other Input Parameters (i.e., Single Simulation)
  – No Uncertainties Considered

• Probabilistic
  – Analyses for Multiple Simulations
  – Accounts for Uncertainties in Earthquake Occurrences and in Estimation of Hazards and Component Performance
SYSTEM ANALYSIS (SINGLE SIMULATION)

Initialization

(System Analysis for Each Simulation)

- Estimate Seismic Hazards at Each Component Site
- Estimate Each Component’s Traffic State
- Estimate System States
- Estimate System-Wide Travel Times
- Estimate Losses from EQ Damage
SYSTEM ANALYSIS (SINGLE SIMULATION)
Estimate Seismic Hazards at Each Component Site

• Ground Motions
  – Use Any Model in REDARS Library
  – Now includes Models for CA and CUS
  – Models for Other Regions to be Added

• Liquefaction
  – At Potentially Liquefiable Sites
  – From User’s Geologic Screening and Soil Properties

• Surface Fault Rupture
  – Along Faults within Roadway System
  – Fault Attributes in Walkthrough Table
SYSTEM ANALYSIS (SINGLE SIMULATION)
Estimate Each Component’s Seismic Performance

- Component Types
  - Bridges
  - Approach Fills
  - Roadways
  - Tunnels

- Estimate Seismic Performance
  - Damage State
  - Repair Cost/Time
  - Traffic State
SYSTEM ANALYSIS (SINGLE SIMULATION)
Estimate System States

- Incorporate each Component’s Traffic State at Each Post-EQ Time into Network Model
- System States Change over Time after EQ
SYSTEM ANALYSIS (SINGLE SIMULATION)  
Estimate System-Wide Travel Times and Traffic Flows

- Apply Network Analysis to Each Post-EQ System State

- Estimates how EQ-Damage to Roadway System Affects
  - Travel Times
  - Traffic-Flows
  - Trip Demands

<table>
<thead>
<tr>
<th>Days after EQ</th>
<th>Travel Time Increase</th>
<th>Reduction of No. of Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 days</td>
<td>28%</td>
<td>22%</td>
</tr>
<tr>
<td>60 days</td>
<td>12%</td>
<td>13%</td>
</tr>
<tr>
<td>150 days</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>221 days*</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

* System Recovery Time (SRT) = 222 days
SYSTEM ANALYSIS (SINGLE SIMULATION)
Estimate Losses

- Economic Losses due to:
  - Travel-Time Increases
  - Trip Reductions
  - Repair Costs

- Increases in Travel Time to/from Any Location

- Increases in Travel Time along Any Route

- Reductions in Trips to/from Any Location

<table>
<thead>
<tr>
<th>Time after EQ</th>
<th>Economic Loss/day (million dollars)</th>
<th>Total Economic Loss (billion dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 days</td>
<td>$31.44</td>
<td></td>
</tr>
<tr>
<td>60 days</td>
<td>$3.94</td>
<td>$1.41</td>
</tr>
<tr>
<td>150 days</td>
<td>$1.16</td>
<td></td>
</tr>
<tr>
<td>222 days</td>
<td>$0</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Increase in Access Time (relative to pre-EQ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7-days after EQ</td>
</tr>
<tr>
<td>Medical Center</td>
<td>44.6%</td>
</tr>
<tr>
<td>Major Airport</td>
<td>34.9%</td>
</tr>
<tr>
<td>Downtown City Center</td>
<td>21.6%</td>
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</tbody>
</table>
RISK-ANALYSIS METHODOLOGY

INITIALIZATION
(input data, model parameters)

SYSTEM ANALYSIS
(for i\textsuperscript{th} Simulation)

INCREMENTATION
(to Next Simulation)

AGGREGATION
(of Results from all Simulations)

Next Simulation
INCREMENT & AGGREGATE RESULTS (for Probabilistic Seismic Risk Analysis)

INITIALIZATION

PERFORM SYSTEM ANALYSIS
(for ith year of EQ walkthrough table)

Compute Confidence Intervals (CIs) for Loss Results

Are CIs Acceptable?

Yes → End

No → To Next Year of Walkthrough Table (i = i + 1)

Calculate λ

Variance Reduction Method

(INCREMENT AND AGGREGATE RESULTS)
PROBABILITY SRA:
Los Angeles Highway-Roadway System
PROBABILISTIC RESULTS: System Performance

Economic Losses due to Repair Costs, Travel-Time Delays, and Trips Foregone
OTHER PROBABILISTIC RESULTS: System Performance (at various times after EQ)

- Increase in Travel Times to/from Any User-Designated Locations (e.g., Travel Times to/from UCLA Hospital)

- Increase in Travel Times along Any User-Designated Routes (e.g., Travel Interstate 5 from Burbank to Downtown LA)

- Reduction in Trips to/from User-Designated Locations (e.g., Trips to/from Downtown LA)
PROBABILITY RESULTS:
Component Performance

Compare Relative Vulnerability of Different Bridges
(or Assess Benefits of Retrofit of Single Bridge)
PROBABILISTIC RESULTS: Component (Bridge) Performance

- Probability of Collapse:
  - 1.6% to 3.2%
  - 0.8% to 1.6%
  - 0.4% to 0.8%
  - 0.2% to 0.4%
  - 0.1% to 0.2%
  - 0.0% to 0.1%
PROBABILISTIC RESULTS: Illustrative Decision-Guidance Application

• Objective
  – Show How REDARS 2 can be Used to Guide Seismic-Risk-Reduction Decision Making

• This Example
  – Hindsight Analysis of Actual Caltrans Bridge Retrofits
GOAL: ASSESS ECONOMIC VIABILITY OF COLUMN JACKETING OF 231 BRIDGES

Initial System with 57 Retrofitted Bridges

Proposed Column Jacketing of 231 Additional Bridges
• Financial Yield of Investment:
  – Benefit = Effectiveness of Retrofits in Reducing Present Value of Mean Economic Loss
  – Cost = Cost to Column Jacket 231 Bridges = $11,000,000
  – Compute Benefit-Cost Ratio

• Volatility of Investment:
  – Reduction in Standard Deviation (SD) of Losses due to Retrofit Program = Reduction of Investment Volatility
RESULTS

• Benefit-Cost Ratios

<table>
<thead>
<tr>
<th>Exposure Time</th>
<th>50 Years</th>
<th>75 Years</th>
<th>100 Years</th>
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<tbody>
<tr>
<td>Discount Rate</td>
<td>2.5%</td>
<td>2.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
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<tr>
<td>Benefit-Cost Ratio</td>
<td>3.90</td>
<td>4.45</td>
<td>4.74</td>
</tr>
<tr>
<td></td>
<td>3.19</td>
<td>3.42</td>
<td>3.51</td>
</tr>
<tr>
<td></td>
<td>2.41</td>
<td>2.45</td>
<td>2.46</td>
</tr>
</tbody>
</table>

• Standard Deviation (SD) of Losses
  - Ratio of SD of Losses before and after 231 retrofits = 0.62
PROBABILISTIC RESULTS:
Convergence of Confidence Intervals

Mean Value of Economic Loss
PRESENTATION SCOPE

- REDARS Methodology

Future Directions
WHERE WE ARE NOW:
REDARS 2 Technical Features

• Multidisciplinary

• Decision Guidance Capability

• Probabilistic and Deterministic Analysis Capability

• Modular
  – Readily Accepts New or Updated Models when they become Available
WHERE WE ARE NOW:
REDARS 2 Usability Features

• Clear and Comprehensive User Manuals

• Import Wizard Automates Significant Portion of Input Data

• Default Models and Input Parameters are Changeable by User

• Variety of Possible Outputs
WHERE DO WE GO FROM HERE?

• Software Maintenance and User Support

• Additional Software Applications and Testing

• Technical and Data Updates

• Possible Future Extension to Other Hazards