A Framework for Evaluating Deterioration in Mobility and Resulting Economic Losses Due to Seismic Damage in Transportation Networks

+ work in progress

by

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A Framework for Evaluating Deterioration in Mobility and Resulting Economic Losses Due to Seismic Damage in Transportation Networks

work in progress

collaborators

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A Framework for Evaluating Deterioration in Mobility and Resulting Economic Losses Due to Seismic Damage in Transportation Networks

+ work in progress

sponsors
A Vision for Regional PBSA of Transportation Networks

+ work in progress
Outline

- Motivation and objectives (big picture)
- Vision and scope
- Details of envisioned components
- Some preliminary results and outlook
Big Picture
Why regional assessment?

• Hazards affect regions. The big picture is needed for
  – Actuarial plans (insurance companies)
  – Urban planning & public policy (government)
  – Emergency service planning (1st responders)

• Built environment is highly interconnected
  – Residential neighborhoods, business centers
  – Transportation networks
  – Lifelines (water, power, communications)
Challenges

• Data metadata models
  – Diverse sample population (requires sophisticated—and as of yet non-existent—data harvesting tools)
  – Access to detailed data may be not be possible (requires estimation missing data, machine learning)
  – Processing requires large computational resources (would break records for civil engineers)

• Models decision variables
  – Heterogeneous analysis tools (OpenSees, OpenSHA, PACT)
  – New tech needs to be brought in (data analytics, Bayesian inference, etc.)
Objectives

Develop a (semi-) automated interactive platform that can evaluate seismic vulnerability of complex transportation networks:

1. Generate structural models using data harvested from various sources
2. Carry out site- and structure-specific seismic analyses
3. Evaluate the consequent economic losses at the network-level

Risk framework for a highway network (Miller & Baker, 2015)
Vision and Scope
Details of the Envisioned Components
Regional PBSA of Ordinary Caltrans Bridges Data

Location to Hazard

Analysis to Decision

Decision Variables
- Losses
- Downtime
- Repair Cost
- Retrofit Cost
- Insurance
- etc.

seismic loads
analysis model
fragility curves
Where is the data coming from?

- National Bridge Inventory (NBI) by FHWA
- *Caltrans Bridge Database*
- California Strong Motion Instrumentation Program (CSMIP) Database
Where is the data coming from?

Guideline Documents

• Caltrans Standard Plans
  allow determination of many metadata elements (e.g., abutment seat length, shear-key reinforcement, foundation configuration, etc.)

• Caltrans Seismic Design Criteria Manual (Caltrans SDC)
  provides era-specific information on component and system design

• Aggregation studies
  provides era-specific structural configuration, probability distributions of structural properties

(Mangalathu, 2017)
Where is the data coming from?

Internet Harvesting

• Google Maps/Earth, MapQuest, etc.

can be interrogated online
more on this later ...
Detection of Bridge Locations

1. Read approximate bridge coordinates from NBI.
2. Extract a satellite image of the location corresponding to approximate bridge coordinate.
3. Run a road extraction algorithm to detect roads on the selected image.
4. Generate random points on detected continuous road lines and pass coordinates to Google Roads API.
5. Cross-check route inventory with NBI, then highlight the relevant road line.
6. Prompt user to mark beginning and end points.
Developing the Wireframe Bridge Models

- Create up to 1000 sampling points between user-defined coords.
- Snap points to road centerline curve using Google Maps.
- Determine ground elevations using Google Maps.
- Determine road elevations using Google Maps.
- Establish wireframe bridge model.
- Create virtual cameras from bridge centerline curve using Google Street View.
- Harvest Street View images at each virtual camera location from Google Street View.
- Identify bent locations using stereo pair images.

A typical virtual camera configuration for a curved bridge.

Distance estimation for an object using a stereo pair image.
Determination of Deck Properties

1. Determine deck type, top width of deck and year the structure was built from NBI.
2. Determine desk superelevation profile by combining geometry info. and speed limit data.
3. Estimate bottom width and height by utilizing fuzzy logic edge detection on harvested Street View images.
4. Estimate reinforcement detailing and corresponding structural properties.
Determination of Column Properties

21.2.1.2 Column Reinforcement Requirements

(1) Longitudinal Reinforcement

Maximum Longitudinal Reinforcement Area, $A_{lr,max} = 0.04 \times A_g$ (SDC 3.7.1-1)

Minimum Longitudinal Reinforcement Area:

$A_{lr,min} = 0.01(A_g)$ for columns (SDC 3.7.2-1)

$A_{lr,min} = 0.005(A_g)$ for Pier walls (SDC 3.7.2-2)

where:

$A_g = \text{the gross cross sectional area (in}^2)$

Normally, choosing column $A_g = 0.015(A_g)$ is a good starting point.

(2) Transverse Reinforcement

Either spirals or hoops can be used as transverse reinforcement in the column. However, hoops are preferred (see MTD 20-9) because of their discrete nature in the case of local failure.

Determine the column type based on the number of detected column edges

Sample column height and width at a number of levels

Estimate rebar detailing and corresponding structural properties by interrogating a database of similar columns (and by utilizing Caltrans SDC)
Completion of model using metadata harvested from the databases and estimates from aggregation studies

Abutment types

Column bearing types

Shear key types and locations

Complete model

Data to be refined by utilizing meta-data rules learned from Caltrans Standard Plans, Caltrans SDC via Deep Learning
Regional PBSA of Ordinary Caltrans Bridges

Image to Model

Location to Hazard

Analysis to Decision

Decision Variables
- Losses
- Downtime
- Repair Cost
- Retrofit Cost
- Insurance
- etc.

seismic loads

analysis model

fragility curves
Probabilistic Seismic Hazard Assessment (PSHA)

A map of active faults around a Los Angeles site (Stewart, 2014)

Basic seismic hazard methodology (from Boore et al.)
Analysis Models
Building blocks of a bridge model

- Piles [Boulanger et al., 1999; Taciroglu et al., 2006; Khalili-Tehrani et al., 2014]
- Abutments [Stewart et al. 2007; Shamsabadi et al., 2010; Nojoumi et al., 2015]
- Shear keys [Mobasher et al., 2015; Omrani et al., 2015]
- In-span hinges [Trochalakis et al., 1997; Hube and Mosalam, 2008]
- Columns [Barry and Eberhard, 2008]
- Girders, deck (elastic)

Detailed descriptions of component and system modeling are provided in
Analysis yields ...

Monte Carlo (on cloud)

Engineering Demand Parameter (EDP)
Analysis yields ...

Probability of Collapse
{Collapse, Extensive, Moderate, Minor}

Fragility Curve

Abutment Skew Angle = 30°
Loss & Recovery Estimation

an open problem for bridges
• Damage to a bridge leads to casualties and functional loss

  Direct losses (repair cost) and indirect losses (downtime and casualties)

• Extensive research had been carried out for buildings
  - EDP to direct and indirect losses (e.g., Porter, 2007; Mitrani-Reiser, 2007)
  - Packaged into FEMA Performance Assessment Calculation Tool (PACT)
  - Provides fragilities/performance-functions for structural and non-structural components, and systems
EDP or Performance State to Loss & Downtime

- Similar capabilities in loss estimation for bridges are lacking
- We currently use ATC-13 Bridge Restoration Curves
A Validation Study
San Bernardino – I-10/I-215 Interchange Bridge
Coronado Bridge, San Diego CA
Validation study

San Bernardino – I-10/I-215 Interchange Bridge

CGS CSMIP-23631
San Bernardino - I10/215 Interchange Br
Validation study

Selection of random points on the bridge by the user
Validation study

Initial processing of selected points by program

Calculation of bridge centerline curve

*Using UCLA automated image-based structural model development program through utilization of

Google Maps Elevation API

Determination of ground elevations

*Using UCLA automated image-based structural model development program through utilization of

Google Maps Roads API

Determination of road elevations

*Using UCLA automated image-based structural model development program through utilization of

MapQuest Directions API
Validation study

Image processing to identify bent locations and developing the wireframe model

Identification of bent locations

*Using UCLA automated image-based structural model development program via Image Analyzer Module

Establishing of wireframe model

*Using UCLA automated image-based structural model development program via Wireframe Model Builder Module
Validation study

Image processing to identify in-span hinge locations

Identification of in-span hinge locations

*Using UCLA automated image-based structural model development program via Image Analyzer Module
Validation study

Using of auxiliary data to determine superelevation profile*

1. Identify centerline geometry in terms of constituent curves/spirals.
2. Get bridge speed limit data through Google Roads API.
3. Estimate curve superelevation at each sampling point.

Determination of curve superelevation at each sampling point

**Using UCLA automated image-based structural model development program via Image Analyzer Module**
Validation study

Determination of bridge column dimensions

Detection of column edges

*Using UCLA automated image-based structural model development program via Fuzzy Logic Edge Detection Module

Determination of column dimensions

*Using UCLA automated image-based structural model development program via Pixel Counter Module
Validation study

Resulting model
Validation study

Resulting model
Validation study

harvested data vs. as-built: bridge deck elevation

![Graph showing comparison between actual measurements and harvested data for bridge deck elevation. The graph includes a line for actual measurements and a line for harvested data, with measurements recorded at various distances along the bridge.]
Validation study

harvested data vs. as-built: column diameters

<table>
<thead>
<tr>
<th>Bent Number</th>
<th>Cylindrical Part - Actual</th>
<th>Cylindrical Part - Harvested</th>
<th>Top Part - Actual</th>
<th>Top Part - Harvested</th>
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<tr>
<td>Bent#2</td>
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</tbody>
</table>
Validation study

harvested data vs. as-built: column heights

- Column Height (ft)
- Bent Number
- Actual Measurements
- Harvested Data
Validation study

harvested data vs. as-built: modal periods

<table>
<thead>
<tr>
<th>Mode</th>
<th>$T_{\text{Image-Based}}$ (sec)</th>
<th>$T_{\text{As-Built}}$ (sec)</th>
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<tbody>
<tr>
<td>Mode 1</td>
<td>1.357</td>
<td>1.528</td>
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<tr>
<td>Mode 2</td>
<td>1.182</td>
<td>1.294</td>
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<td>Mode 3</td>
<td>1.028</td>
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<td>Mode 4</td>
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<td>Mode 5</td>
<td>0.892</td>
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<tr>
<td>Mode 6</td>
<td>0.836</td>
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<td>Mode 7</td>
<td>0.784</td>
<td>0.807</td>
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<tr>
<td>Mode 8</td>
<td>0.746</td>
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</tbody>
</table>
Validation study

harvested data vs. as-built: mode shapes

Mode 1

Mode 2

Mode 3

Image-Based

As-Built
Other Examples
Sample Application: LA I10/I405N Interchange
Sample Application: LA Wilshire/I-405N On-Ramp
Sample Application: LA I405N/CA22W Interchange
Regional Assessment
Application Example
Port of Los Angeles
Region of Interest

Port of Los Angeles

- 5x6 miles rectangular region containing all critical bridges connecting to Port of Los Angeles
- ROI contains 95 bridges
- 62 bridges built <1970 and have not been retrofitted
Bridge Model Inventory

• Geometries generated with UCLA tool from street view + satellite images

• Structural properties are assigned probabilistically based on a Georgia Tech study of California bridges (Mangalathu, 2017)

• The study contains statistical distributions for
  ‣ Concrete compressive strength*
  ‣ Steel yield strength*
  ‣ Longitudinal steel reinforcement ratio
  ‣ Transverse steel reinforcement ratio*
  ‣ Foundation translation and rotational stiffness*
  ‣ Damping
  ‣ Mass factor

<table>
<thead>
<tr>
<th>Design Era</th>
<th>Type</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
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<td>Era 1</td>
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<td>0.07</td>
<td>0.4</td>
<td>0.14</td>
</tr>
<tr>
<td>Era 2/ Era 3</td>
<td>Uniform</td>
<td>0.85</td>
<td>0.07</td>
<td>0.4</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Scenario Event

- Fault: Palos Verdes Connected
- Magnitude: 7.7
- Distance to Port of Los Angeles: 14 miles

SA1 (%g) heat map for Mw=7.7 Palos Verdes Connected Scenario Event
Bridge Closures

3-span bridge
YB=1970, seat abutment

5-span curved bridge
YB=1997, seat abutment
Quo Vadis?

• Further develop Image to Model Capabilities
• Develop user-interface (a GIS-integrated web site)
• Combine bridge closure data with traffic congestion simulation and estimate economic losses (USC collaboration)
• Expand to Region of Interest
• Consider realistic aftershock effects
What about Buildings?
Building models from image data

- Exterior
- Interior typical corridor
- Interior typical room
- Interior-exterior combo
- Resulting model
ShakeReady

a user interface under development
Building inventories
Non-ductile reinforced concrete buildings under a scenario event

Scenario Event: M7.2 Reverse-Slip Earthquake on Puente Hills Fault

>=50%: #735
>=90%: #174
thank you!
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