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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+ 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

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sponsors

Caltrans

PEER

NSF

CGS

CALIFORNIA GEOLOGICAL SURVEY

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

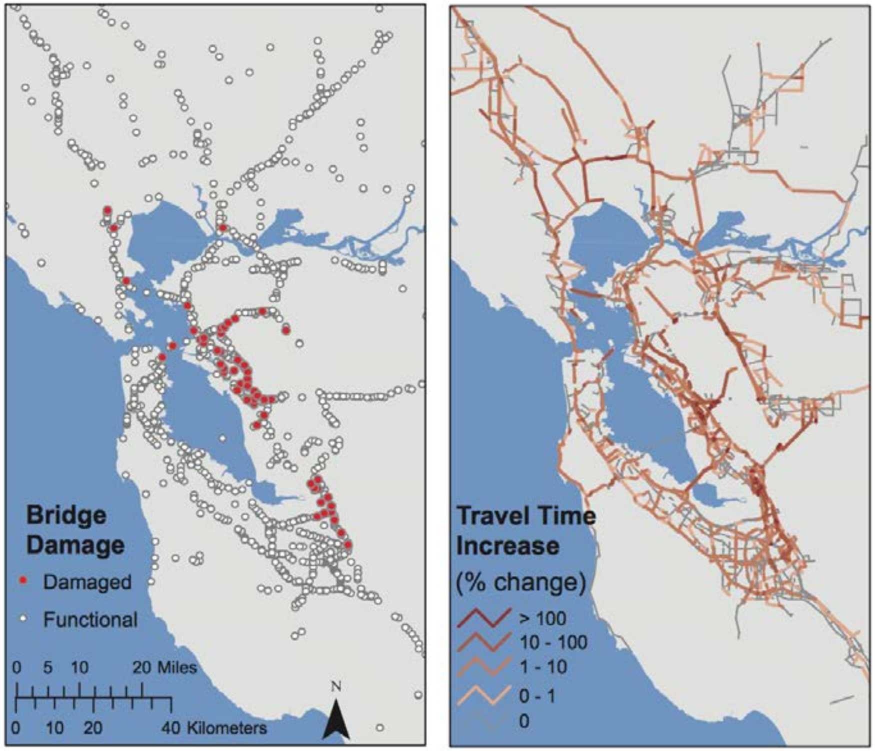
Why regional assessment?

- 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



Risk framework for a highway network (Miller & Baker, 2015)

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

Vision and Scope

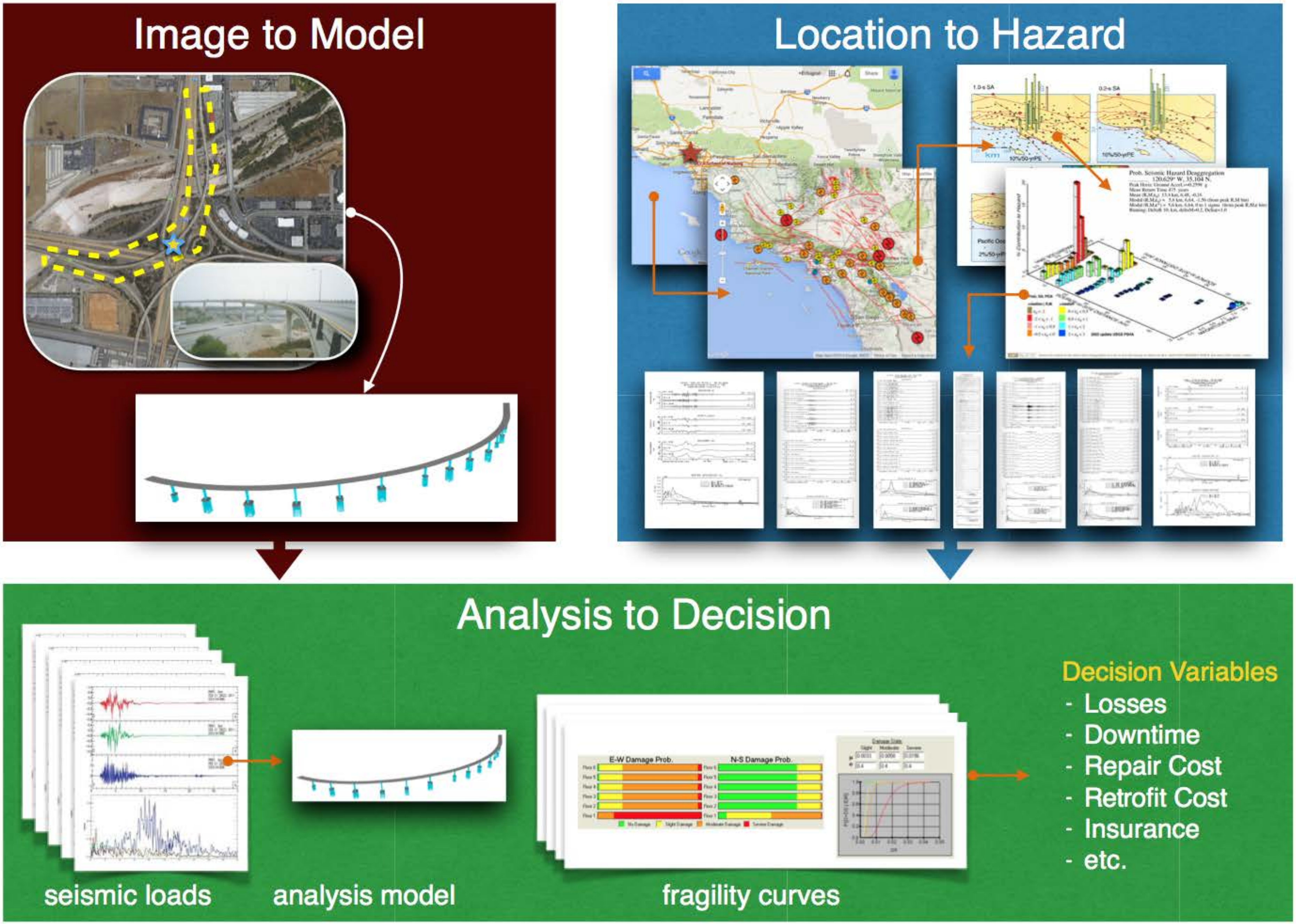
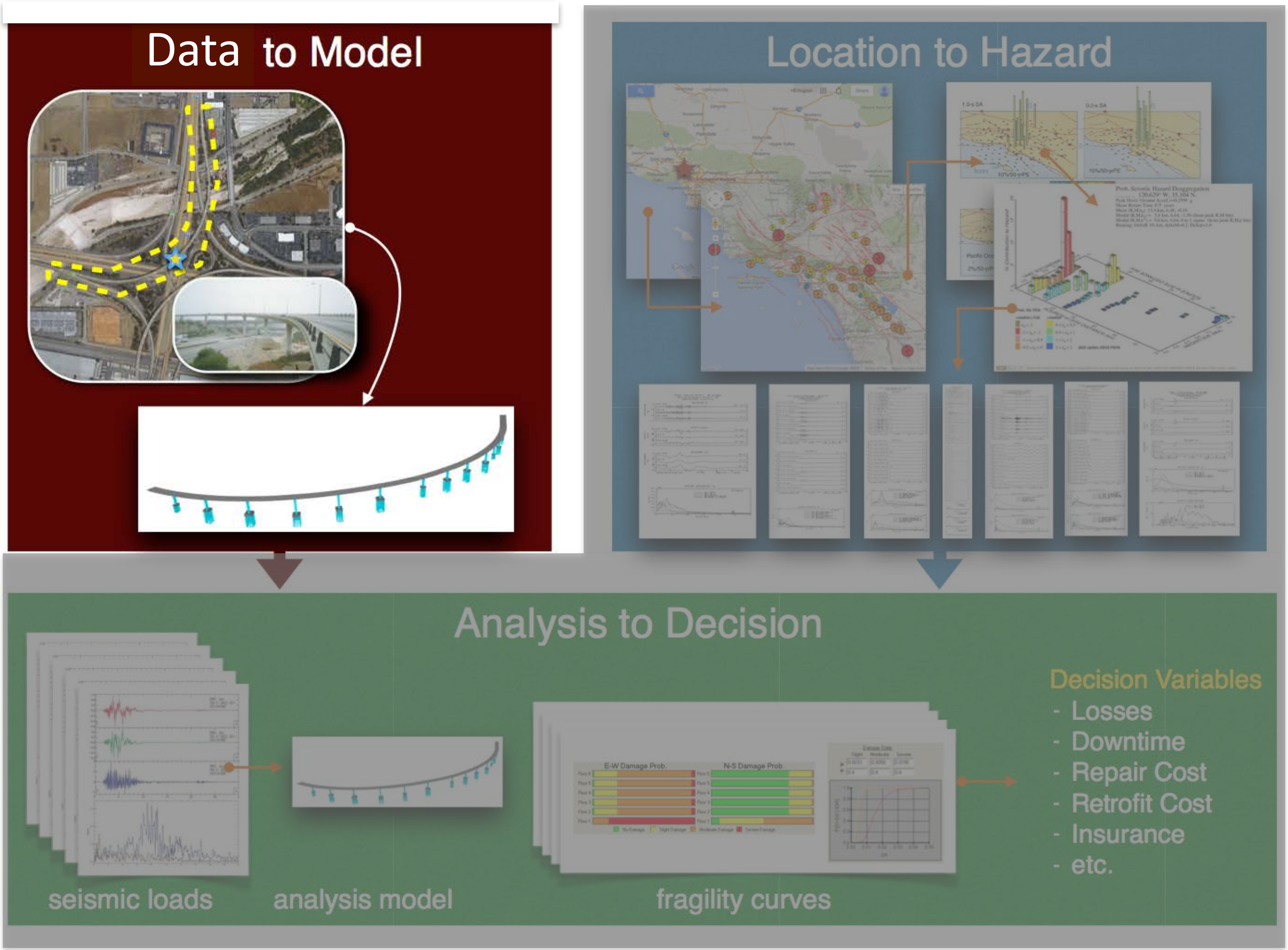


Image to Model
Location to Hazard
Analysis to Decision
Decision Variables
- Losses
- Downtime
- Repair Cost
- Retrofit Cost
- Insurance
- etc.
seismic loads
analysis model
fragility curves


UCLA Regional PBSA Tool
Image and direct metadata from users and public databases
Image-to-Model Module
meta-data-bases for structural system and nonstructural components, loss estimates
compute
commit
visualize
amazon web services
OPEN SHA
NGA W2
OpenSees
FEMA PACT
SCAG RTPSCS
ATC
Google Sketch-up
Google earth

Details of the Envisioned Components


Data to Model
Location to Hazard
Analysis to Decision
E-W Damage Prob.
N-S Damage Prob.
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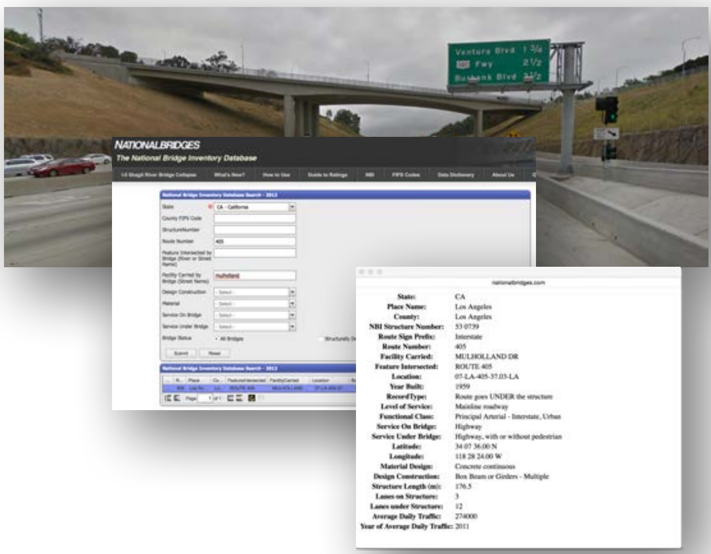
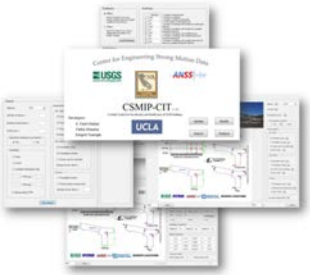
- etc.
seismic loads
analysis model
fragility curves

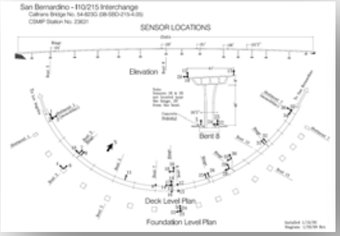
Where is the data coming from?

- National Bridge Inventory (NBI) by FHWA
- *Caltrans Bridge Database*
- California Strong Motion Instrumentation Program (CSMIP) Database



Number of Spans	20
Plan Shape	Straight
Total Length	2507' (764.1m)
Width of Deck	34' (10.4m)
Construction Year	1971
Instrumentation Year	1996
Seismic Retrofit	2006



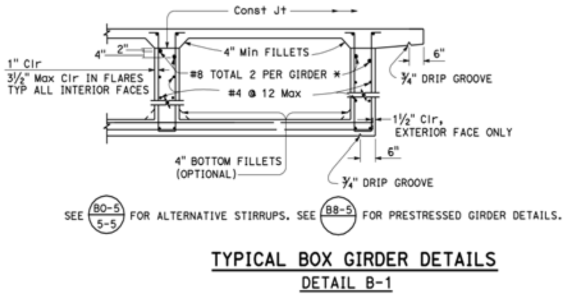


Where is the data coming from?

Guideline Documents

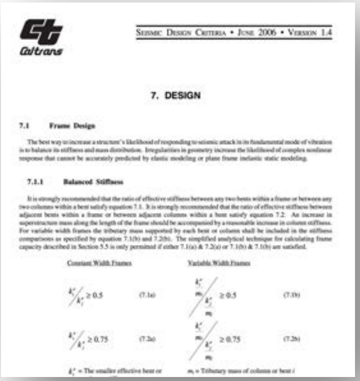
- Caltrans Standard Plans

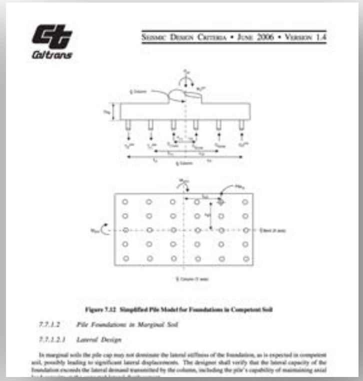
  allow determination of many metadata elements (e.g., abutment seat length, shear-key reinforcement, foundation configuration, etc.)



- 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 …

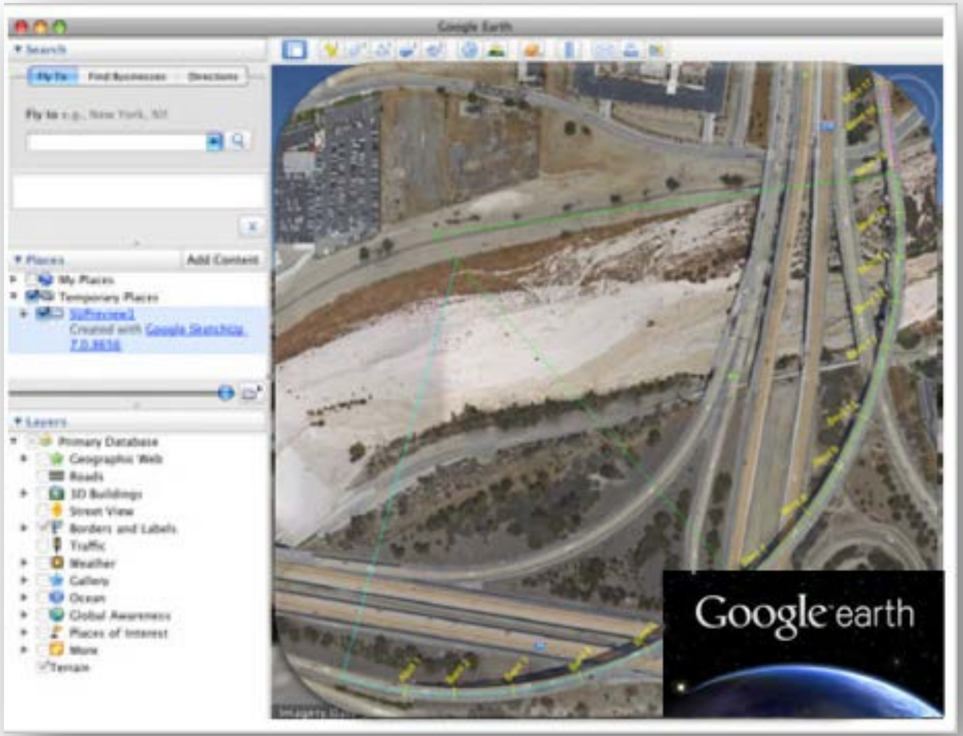


Image to Model

Detection of Bridge Locations

Read approximate bridge coordinates from NBI

Extract a satellite image of the location corresponding to approximate bridge coordinate

Run a road extraction algorithm to detect roads on the selected image

Generate random points on detected continuous road lines and pass coordinates to Google Roads API

Cross-check route inventory with NBI, then highlight the relevant road line

Prompt user to mark beginning and end points

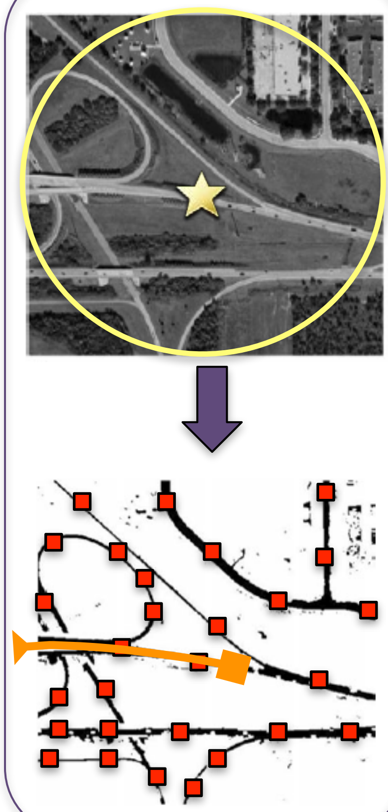


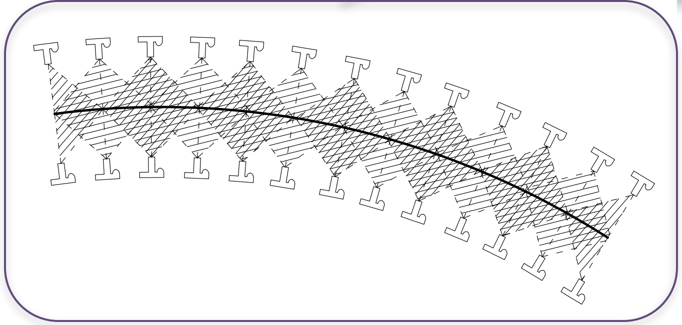
Image to Model

Developing the Wireframe Bridge Models

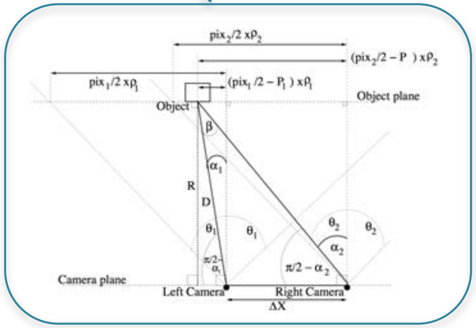
Create up to 1000 sampling points between user-defined coords. → Snap points to road centerline curve using Google Maps → Determine ground elevations using Google Maps → Determine road elevations using MapQuest

Create virtual cameras from bridge centerline curve → Harvest Street View images at each virtual camera location from Google Street View → Identify bent locations using stereo pair images

Establish wireframe bridge model



A typical virtual camera configuration for a curved bridge



Distance estimation for an object using a stereo pair image

Image to Model

Determination of Deck Properties

Determine deck type, top width of deck and year the structure was built from NBI

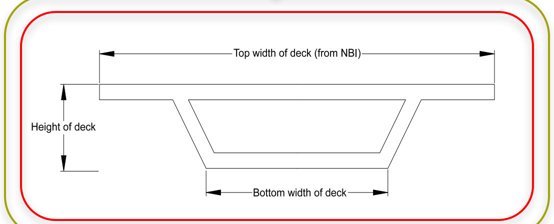
Determine desk superelevation profile by combining geometry info. and speed limit data

Estimate bottom width and height by utilizing fuzzy logic edge detection on harvested Street View images

Estimate reinforcement detailing and corresponding structural properties

Standard Specifications for Highway Bridges

Google Maps



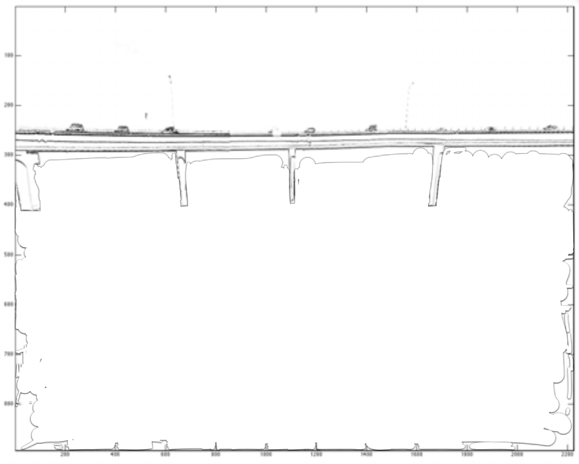


Image to Model

Determination of Column Properties

21.2.1.2 Column Reinforcement Requirements

(1) Longitudinal Reinforcement

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

Minimum Longitudinal Reinforcement Area:

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

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

where:

A_g = the gross cross sectional area (in.^{2})

Normally, choosing column $A_{st} = 0.015(A_g)$ 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)

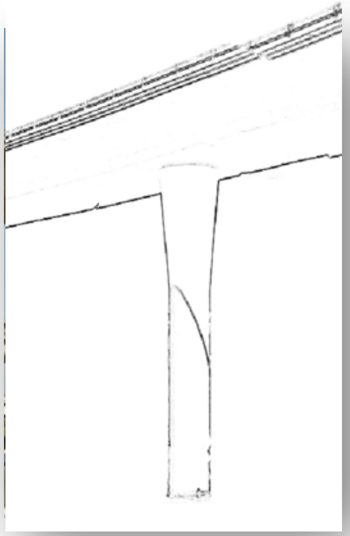


Image to Model

Completion of model using metadata harvested from the databases and estimates from aggregation studies

Abutment types

↓

Column bearing types

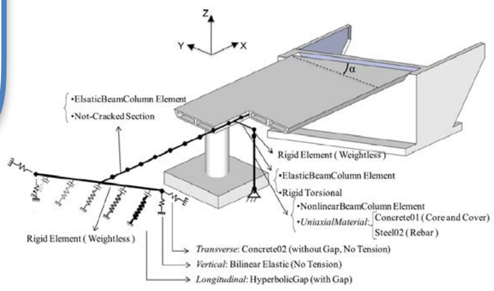
↓

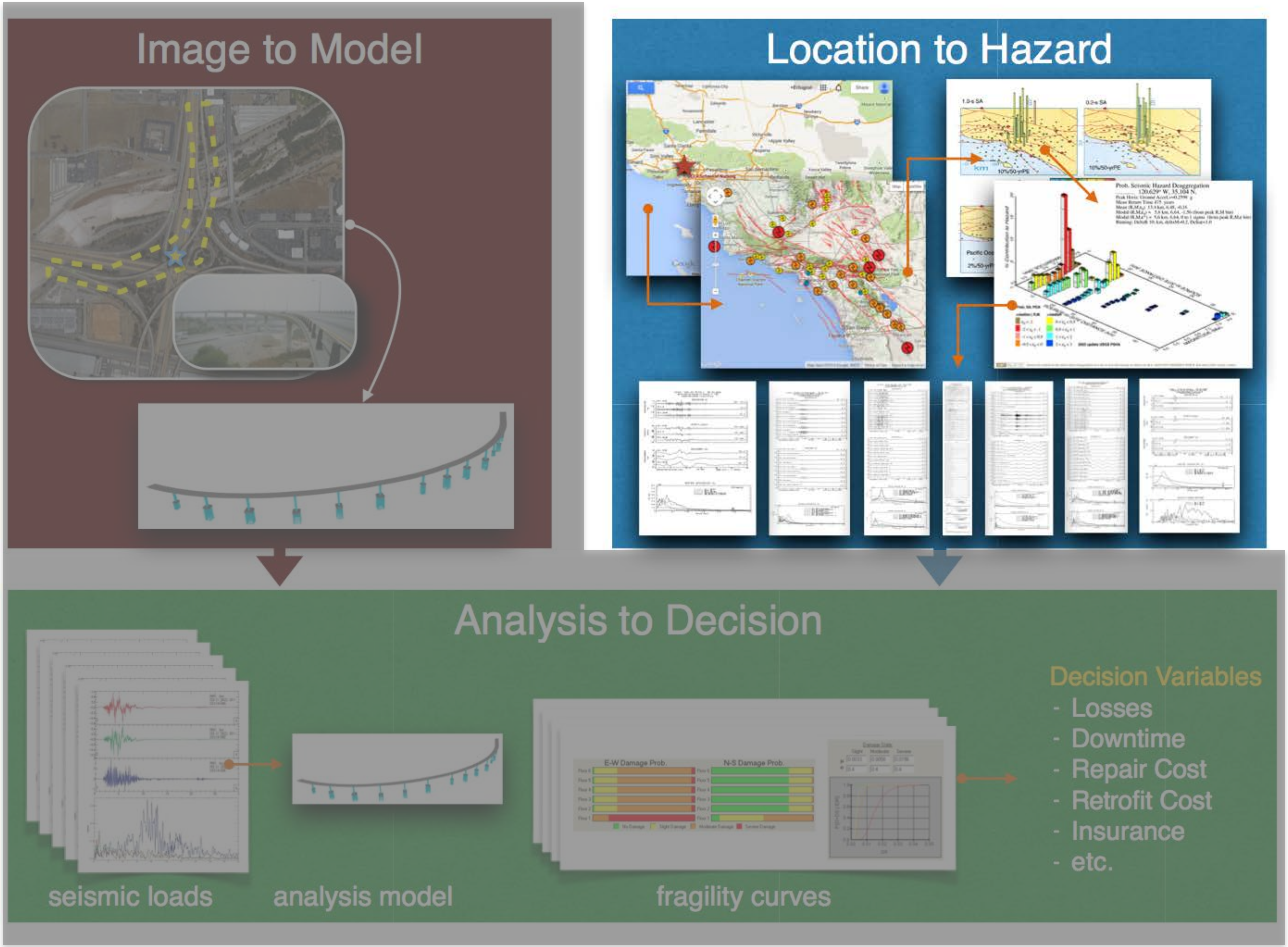
Shear key types and locations

↓

Complete model

Data to be refined by utilizing meta-data rules *learned* from Caltrans Standard Plans, Caltrans SDC via Deep Learning

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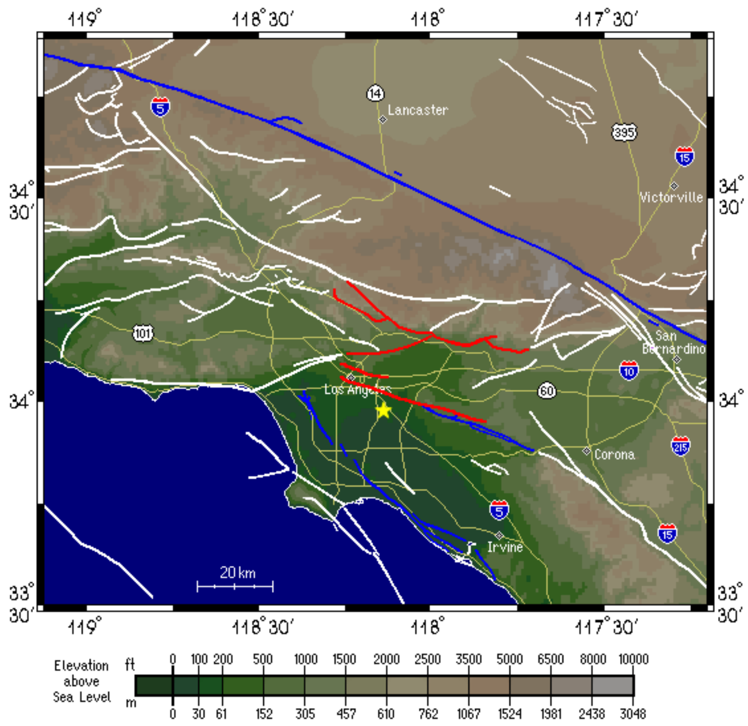
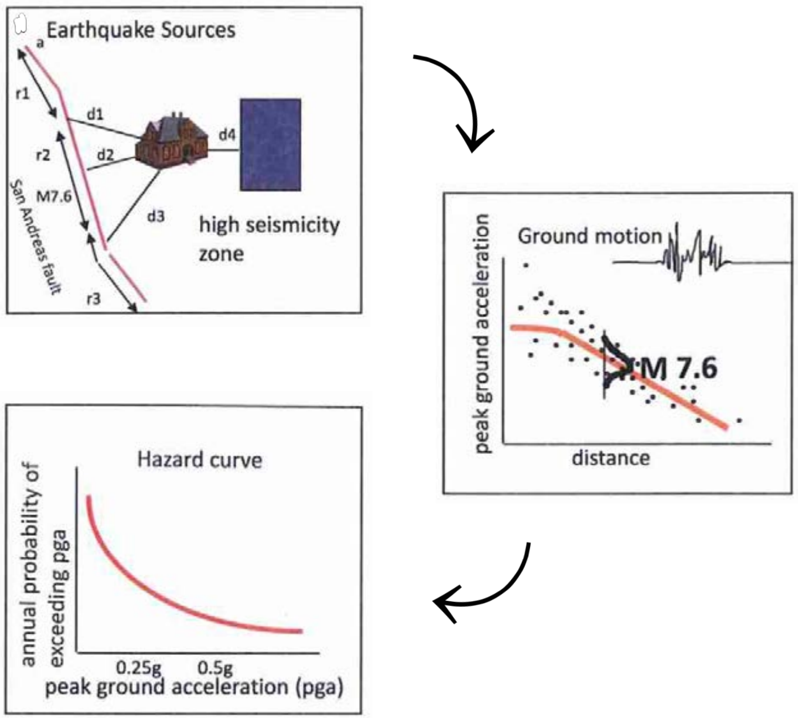
Location to Hazard

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.)

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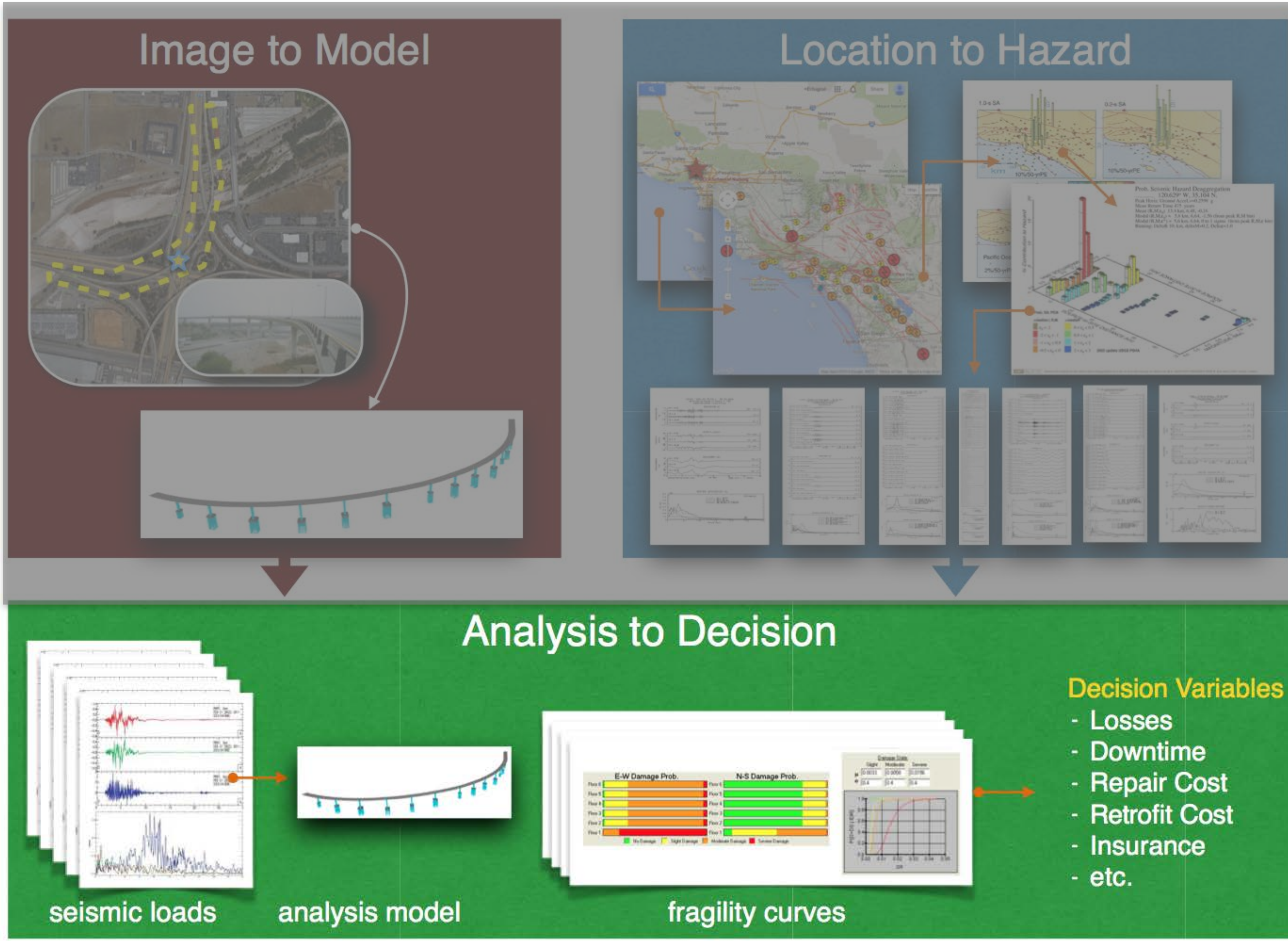
PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

SC/EC
AN NSF+USGS CENTER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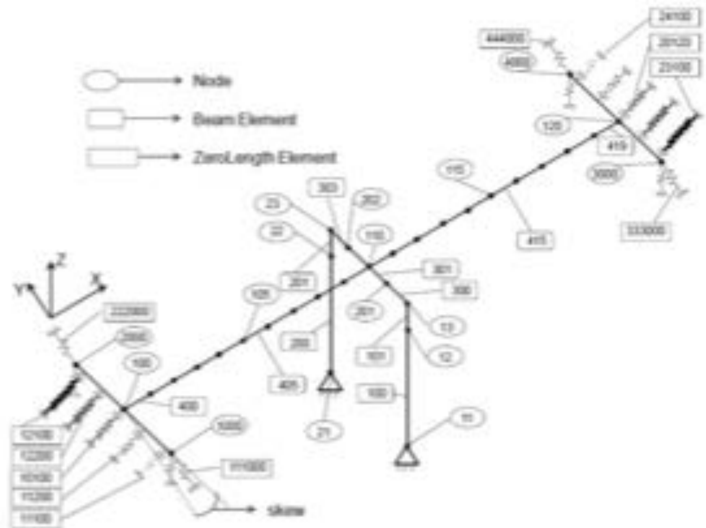
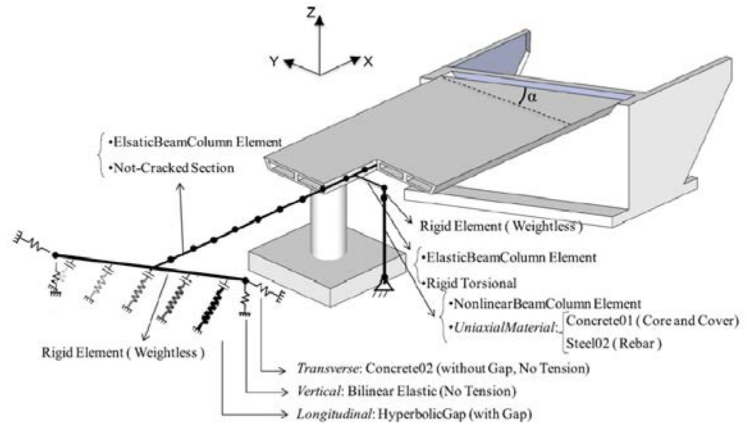
Analysis Models

Building blocks of a bridge model



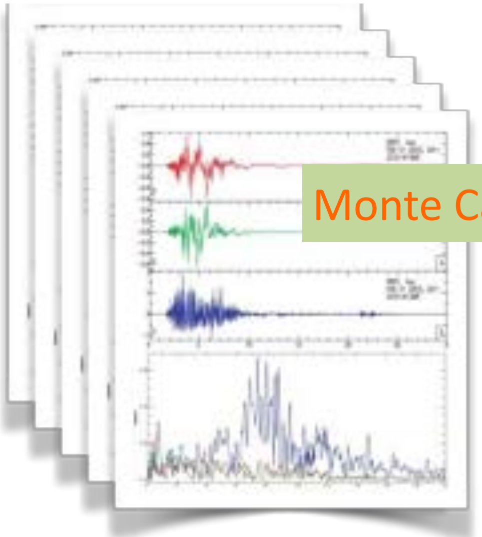


- Piles [Boulanger et al., 1999; Taciroglu et al., 2006; Khalili-Tehrani et al., 2014]
- Abutments [Stewart et al. 2007; Shamsabadi et al., 2010; Nojoumi et al., 2015]
- Shear keys [Mobasher et al., 2015; Omrani et al., 2015]
- In-span hinges [Trochalakis et al., 1997; Hube and Mosalam, 2008]
- Columns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

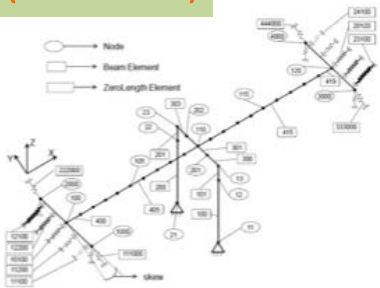
Detailed descriptions of component and system modeling are provided in

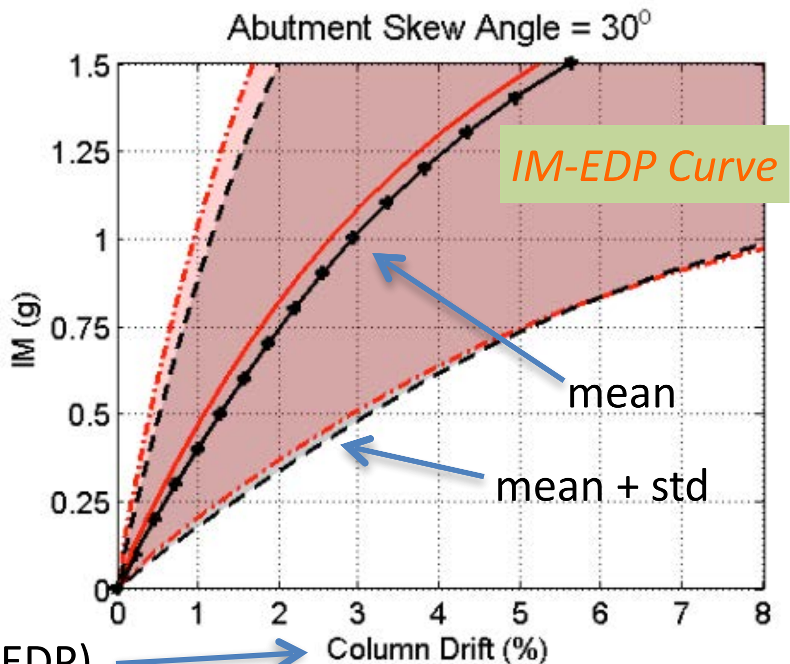
Omrani R, Mobasher B, Liang X, Gunay S, Mosalam K, Zareian F, Taciroglu E (2015). *Guidelines for Nonlinear Seismic Analysis of Ordinary Bridges: Version 2.0*, Caltrans Report No. 15-65A0454, Sacramento CA.

Analysis yields …



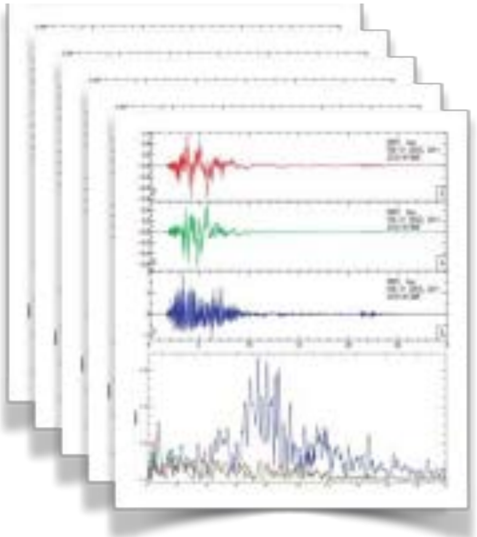
Monte Carlo (on cloud)

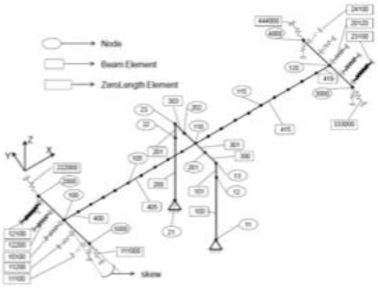




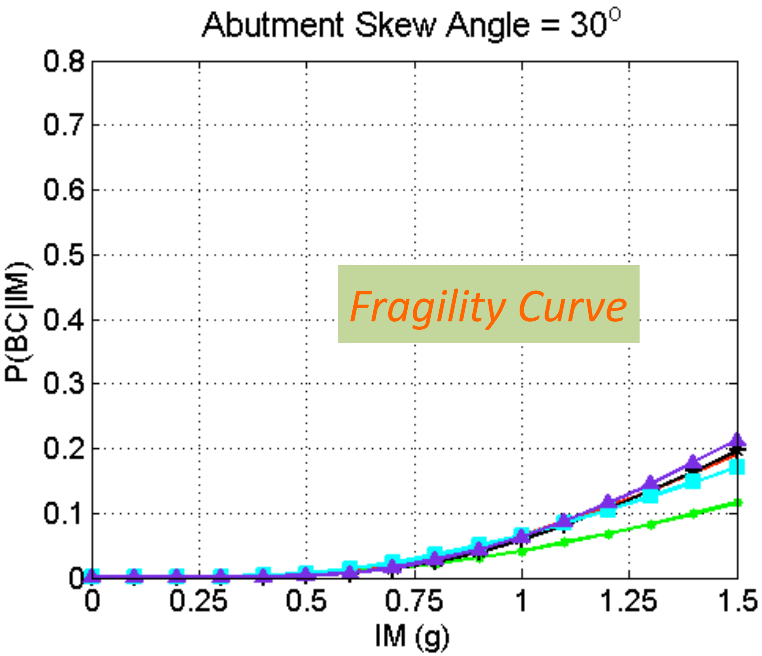
Engineering Demand Parameter (EDP)

Analysis yields …





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



Loss & Recovery Estimation

an open problem for bridges

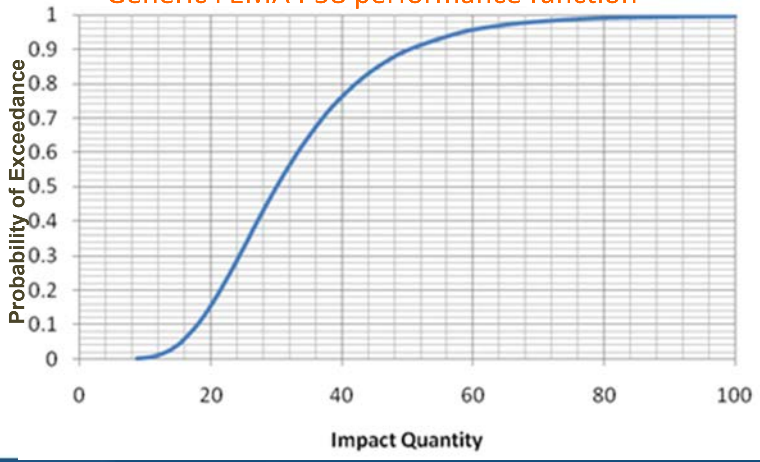
EDP or Performance State to Loss & Downtime

- Damage to a bridge leads to casualties and functional loss

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

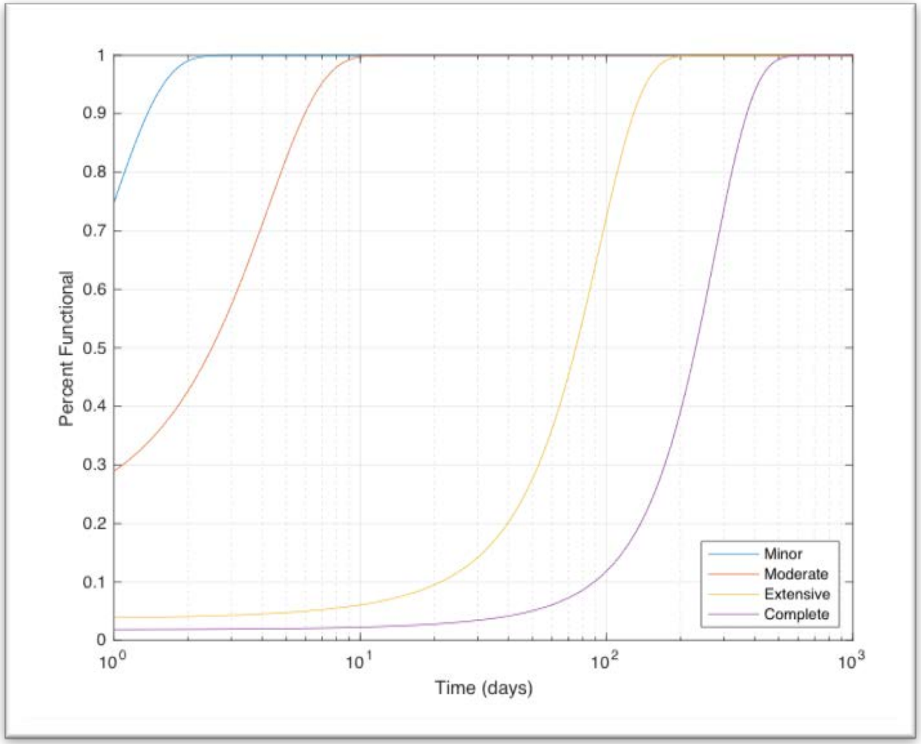
- Extensive research had been carried out for buildings
  - *EDP to direct and indirect Losses (e.g., Porter, 2007; Mitrani-Reiser, 2007)*
  - *Packaged into FEMA Performance Assessment Calculation Tool (PACT)*
  - *Provides fragilities/performance-functions for structural and non-structural components,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

Generic FEMA P58 performance function



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

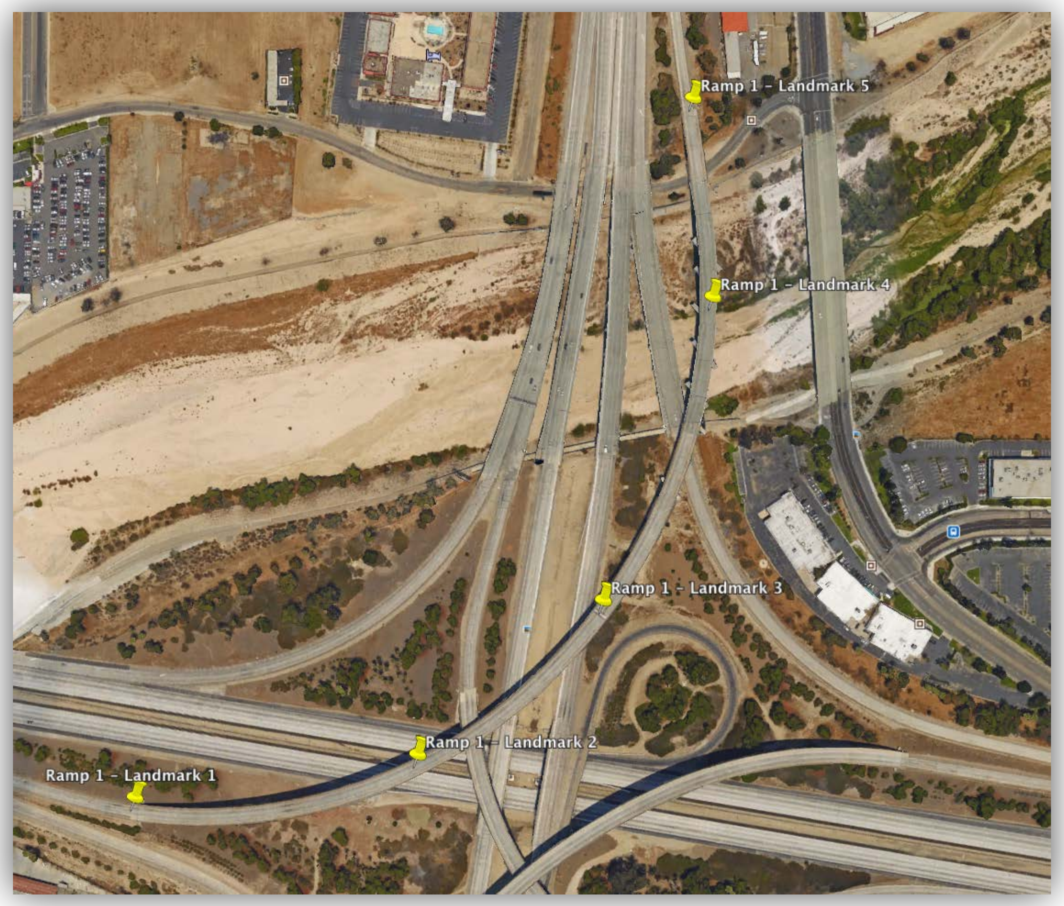
Coronado Bridge, San Diego CA

Validation study

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

Validation study

Selection of random points on the bridge by the user



Validation study

Initial processing of selected points by program

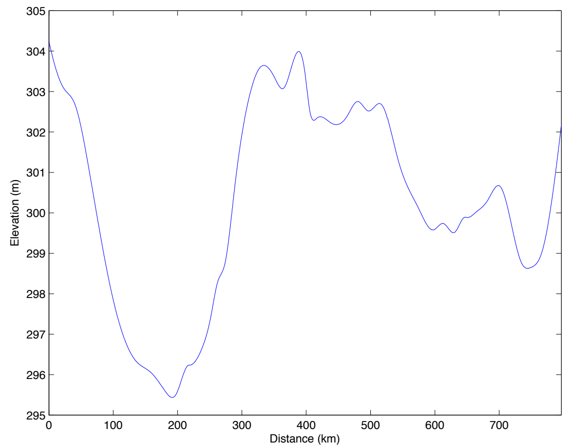
Calculation of bridge centerline curve

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

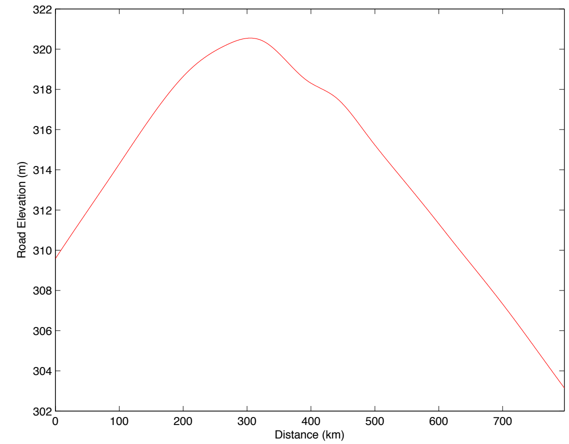
Google Maps Roads API

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

Google Maps Elevation API



Determination of ground elevations



Determination of road elevations

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

MapQuest Directions API

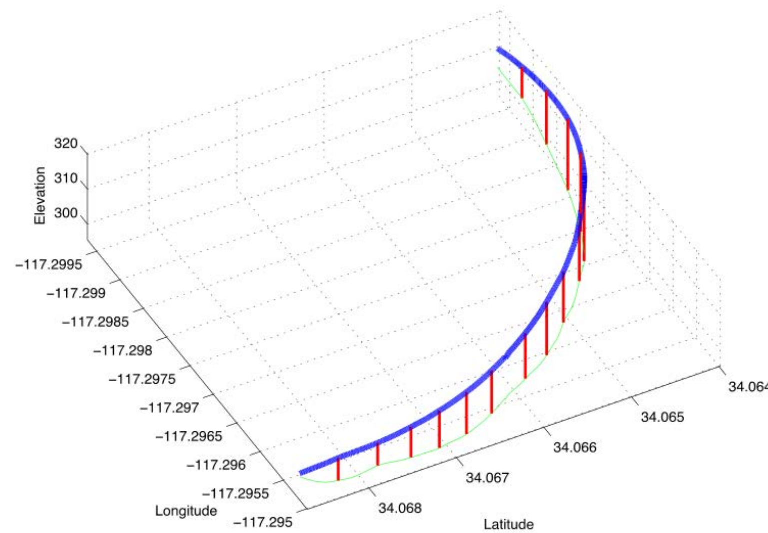
Validation study

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*

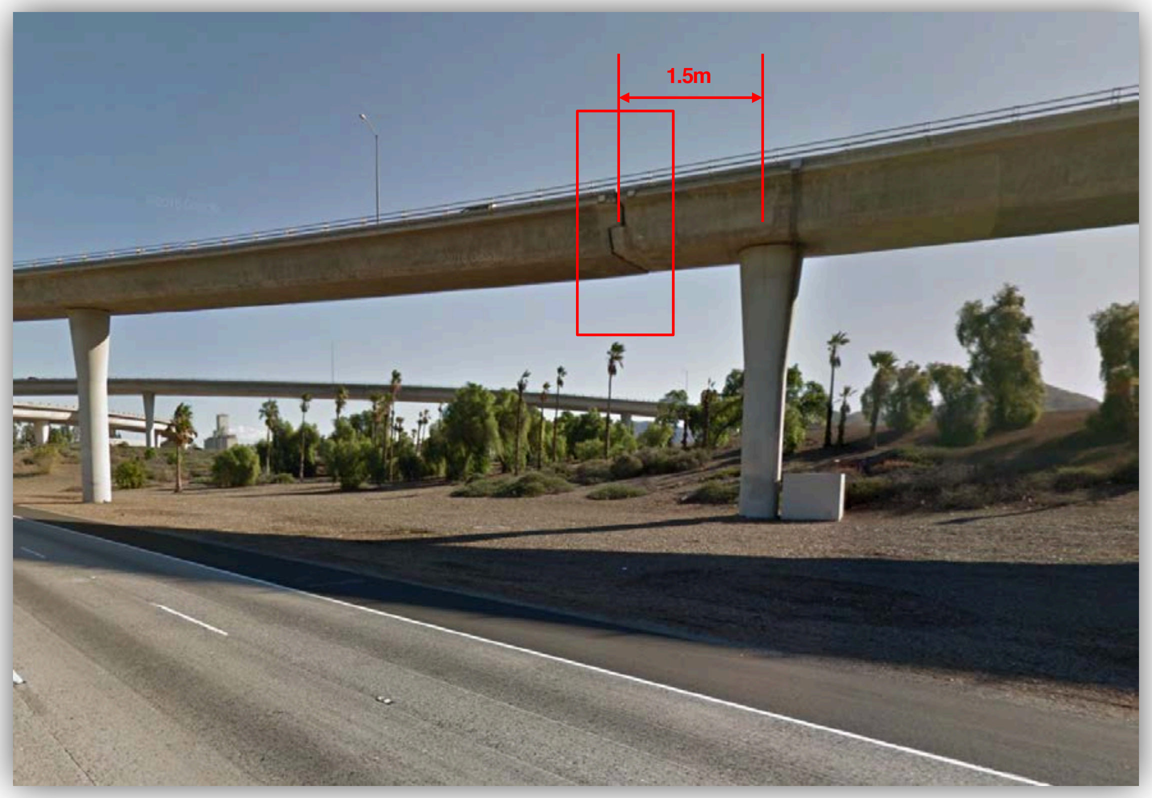
*Using ***UCLA*** automated image-based structural model development program via *Wireframe Model Builder Module*



Establishing of wireframe model

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*

Determination of curve superelevation at each sampling point

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

Identify centerline geometry in terms of constituent curves/spirals.

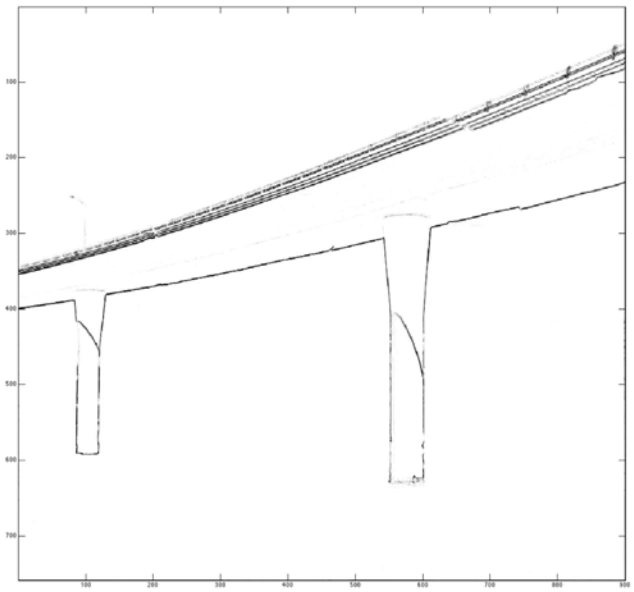
Get bridge speed limit data through Google Roads API.

Estimate curve superelevation at each sampling point.

Basic methodology to determine curve superelevation profile

Validation study

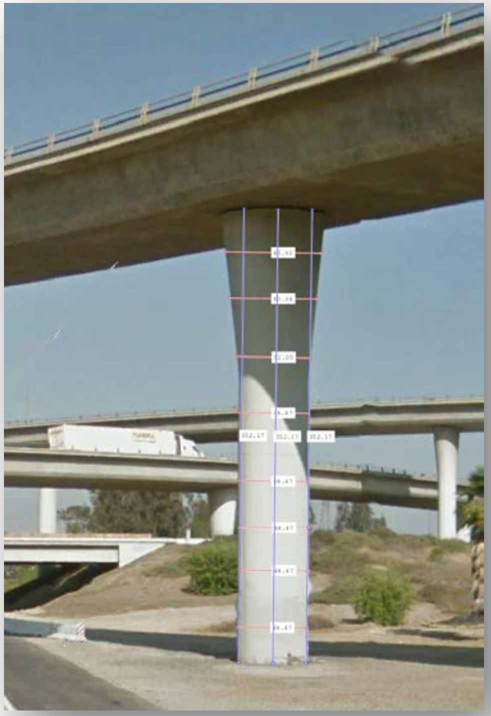
Determination of bridge column dimensions



Detection of column edges

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

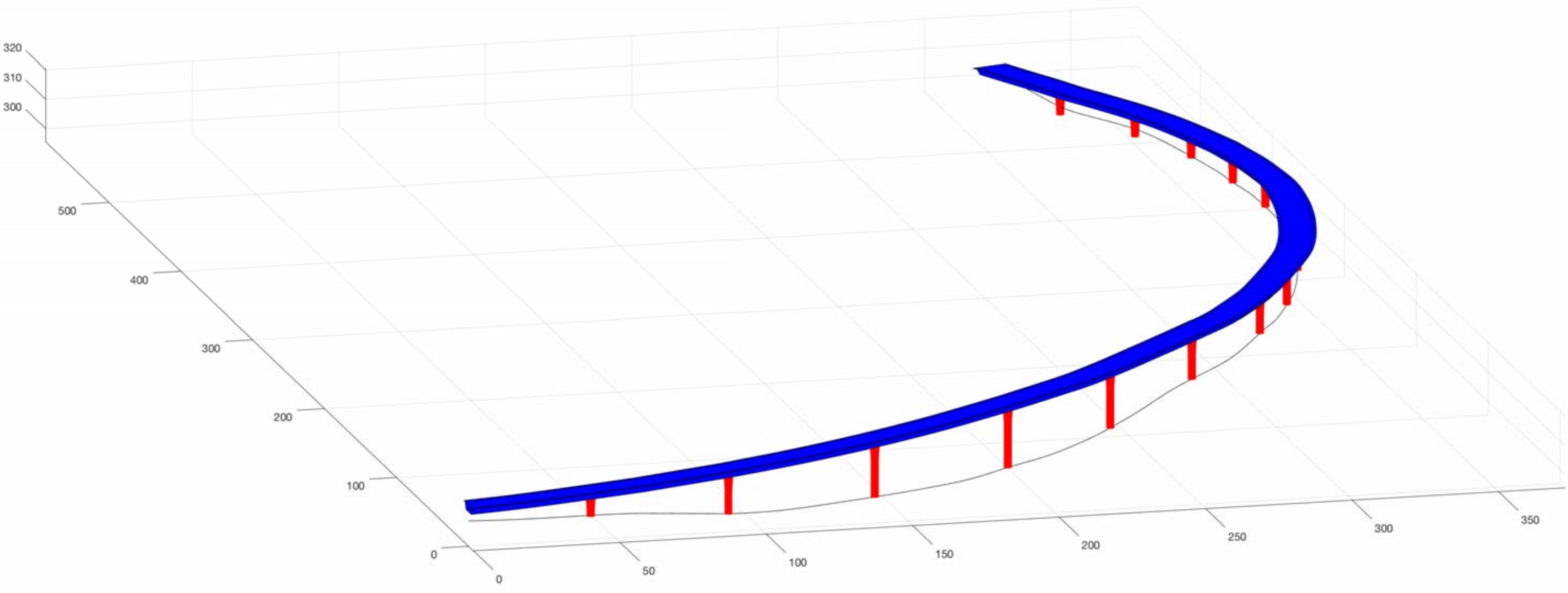
*Using ***UCLA*** automated image-based structural model development program via *Pixel Counter Module*



Determination of column dimensions

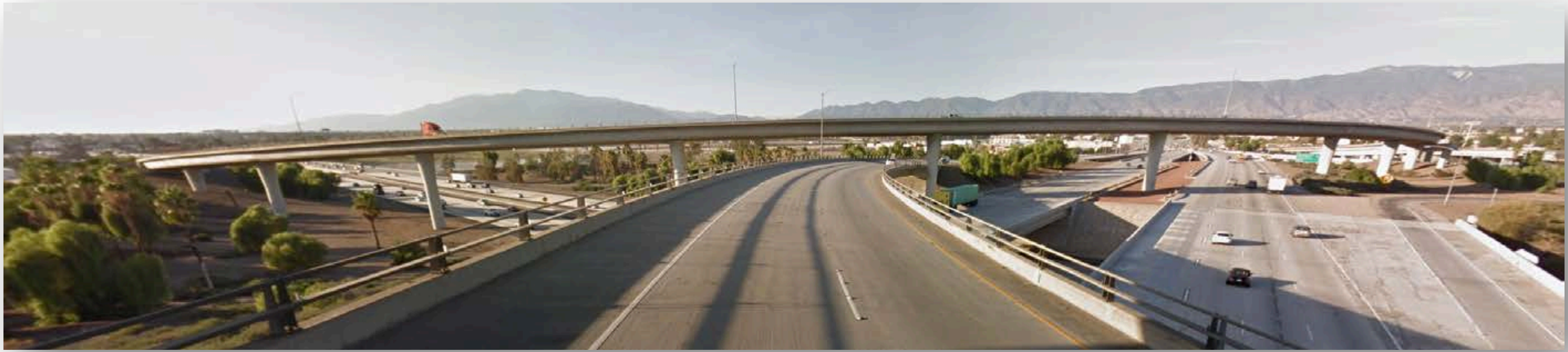
Validation study

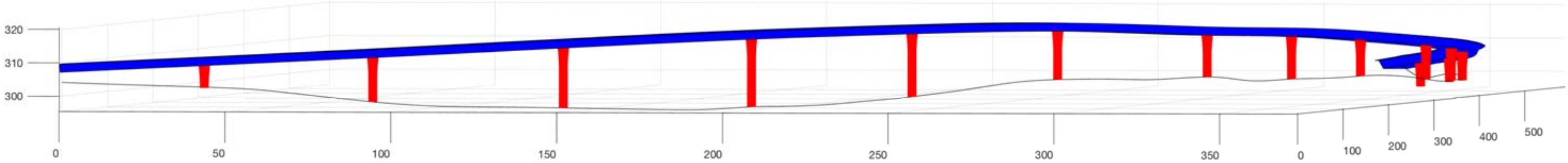
Resulting model



Validation study

Resulting model



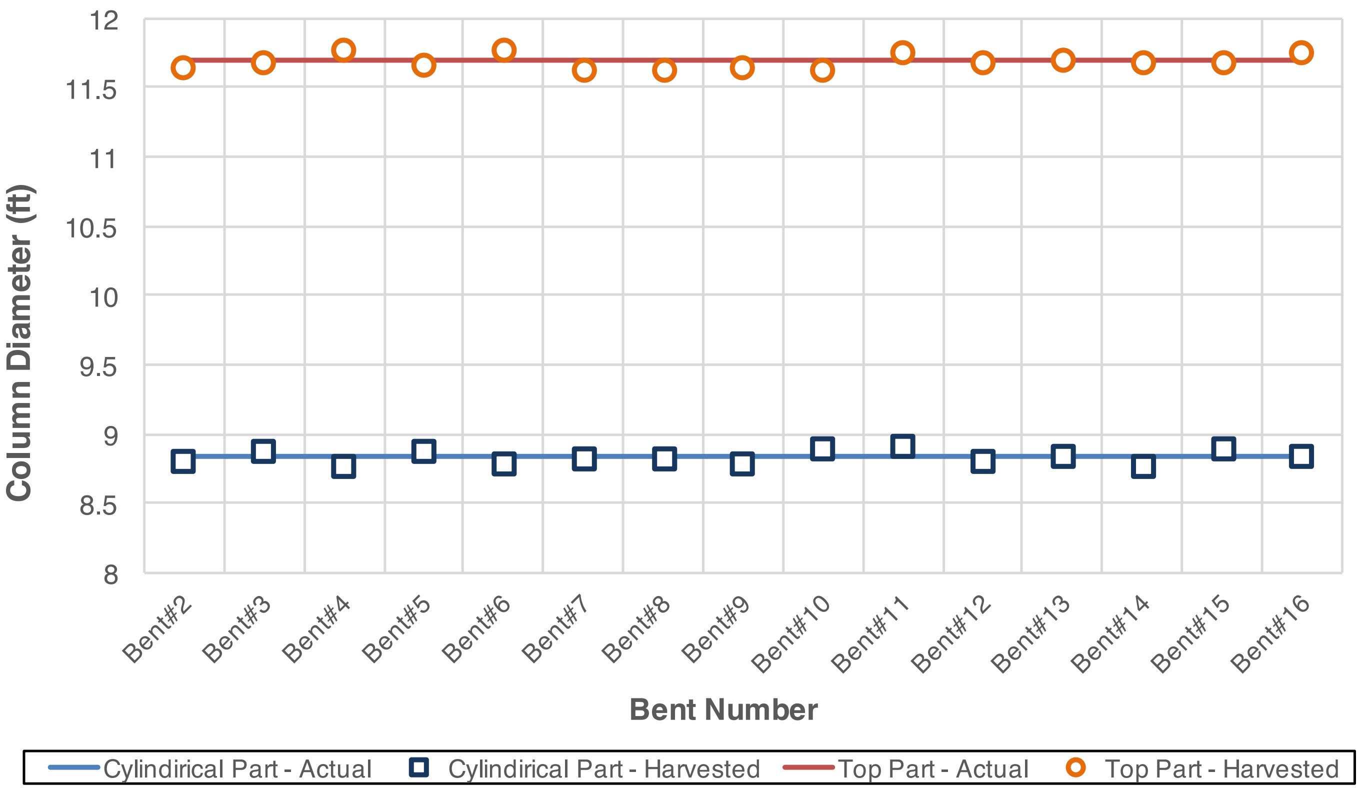


Validation study

harvested data vs. as-built: bridge deck elevation

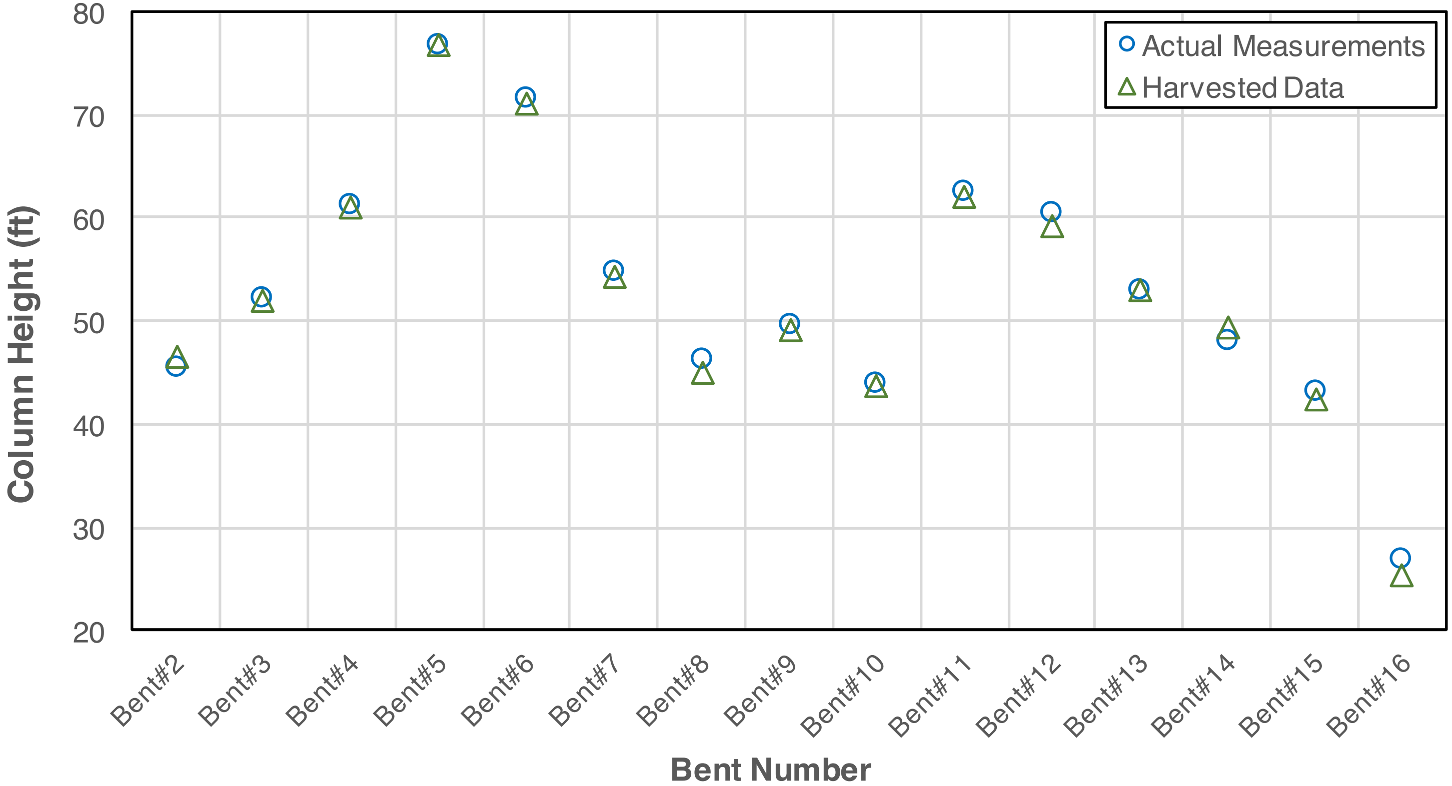
Validation study

harvested data vs. as-built: column diameters



Validation study

harvested data vs. as-built: column heights



Validation study

harvested data vs. as-built: modal periods

	$T_{Image\text{-}Based}$ (sec)	$T_{As\text{-}Built}$ (sec)
Mode 1	1.357	1.528
Mode 2	1.182	1.294
Mode 3	1.028	1.091
Mode 4	0.947	1.019
Mode 5	0.892	0.942
Mode 6	0.836	0.881
Mode 7	0.784	0.807
Mode 8	0.746	0.788

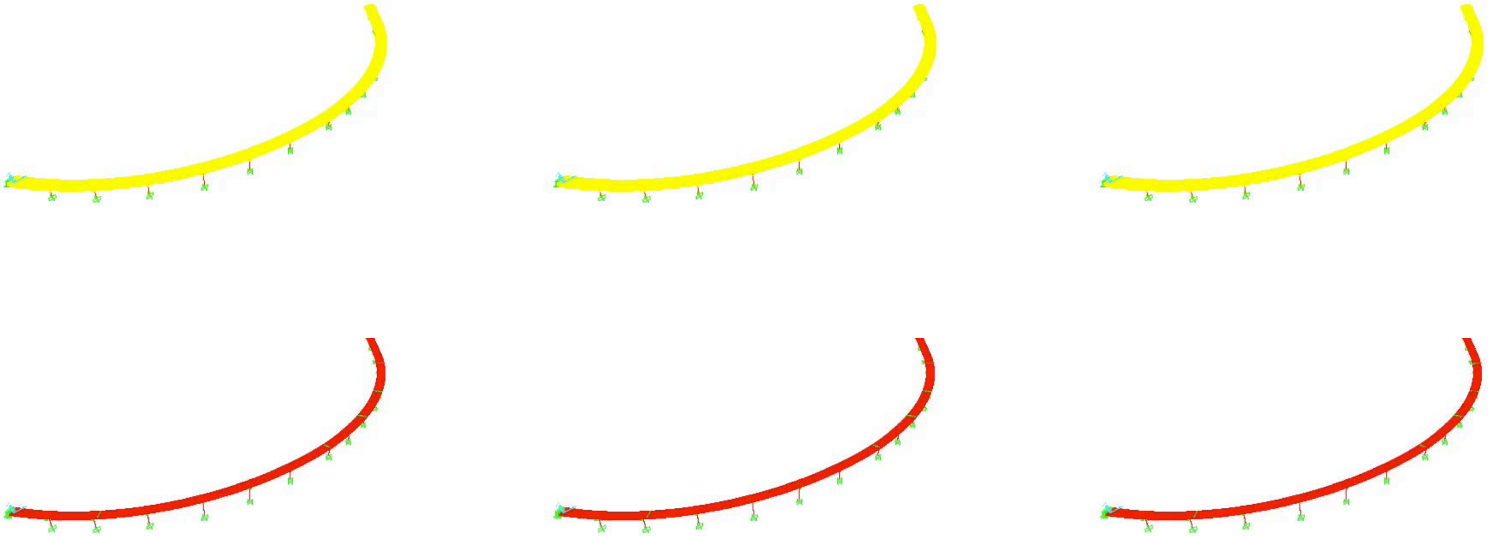
Validation study

harvested data vs. as-built: mode shapes

Mode 1 | Mode 2 | Mode 3

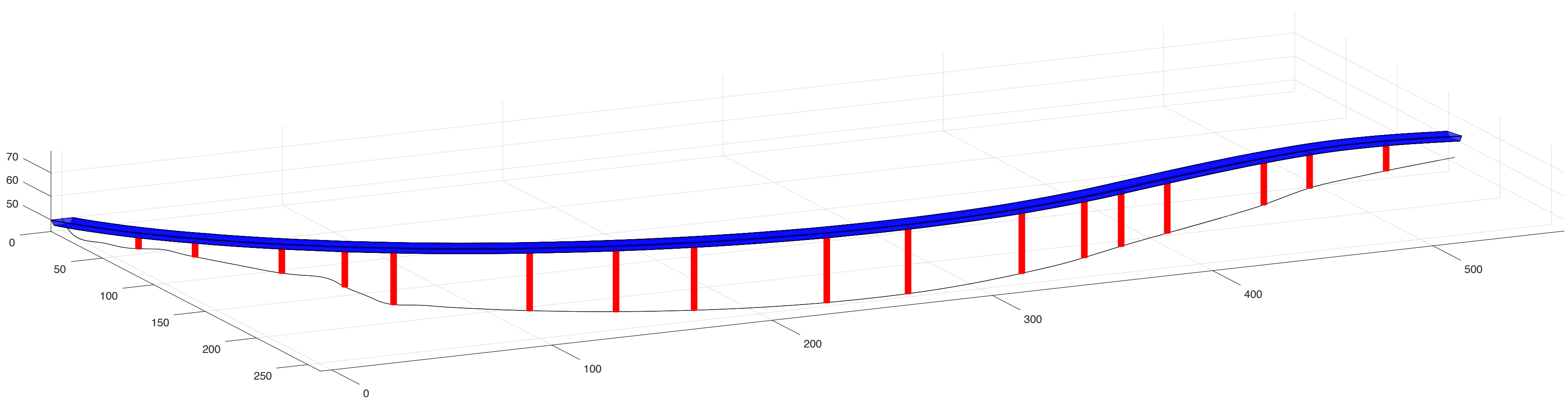
Image-Based

As-Built



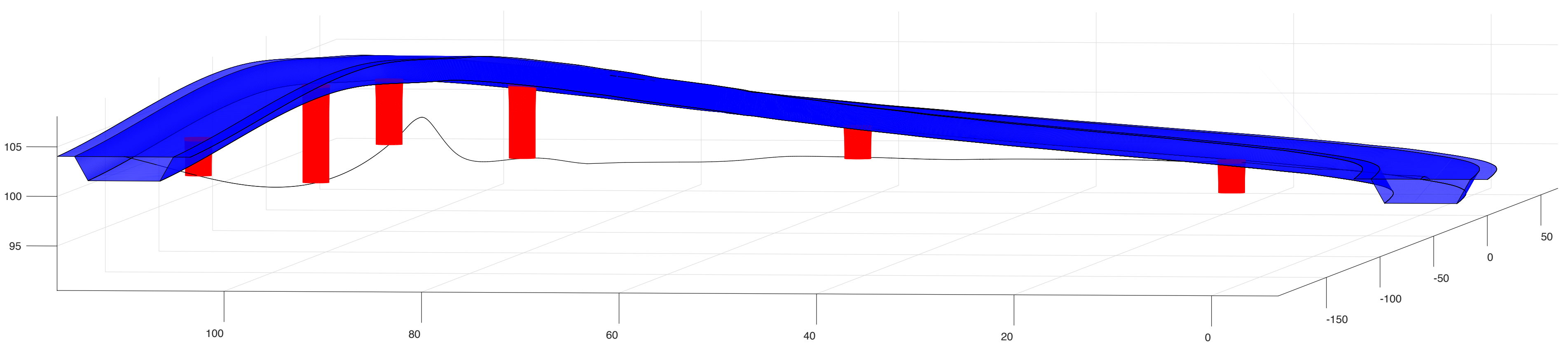
Other Examples

Sample Application: LA I10/I405N Interchange

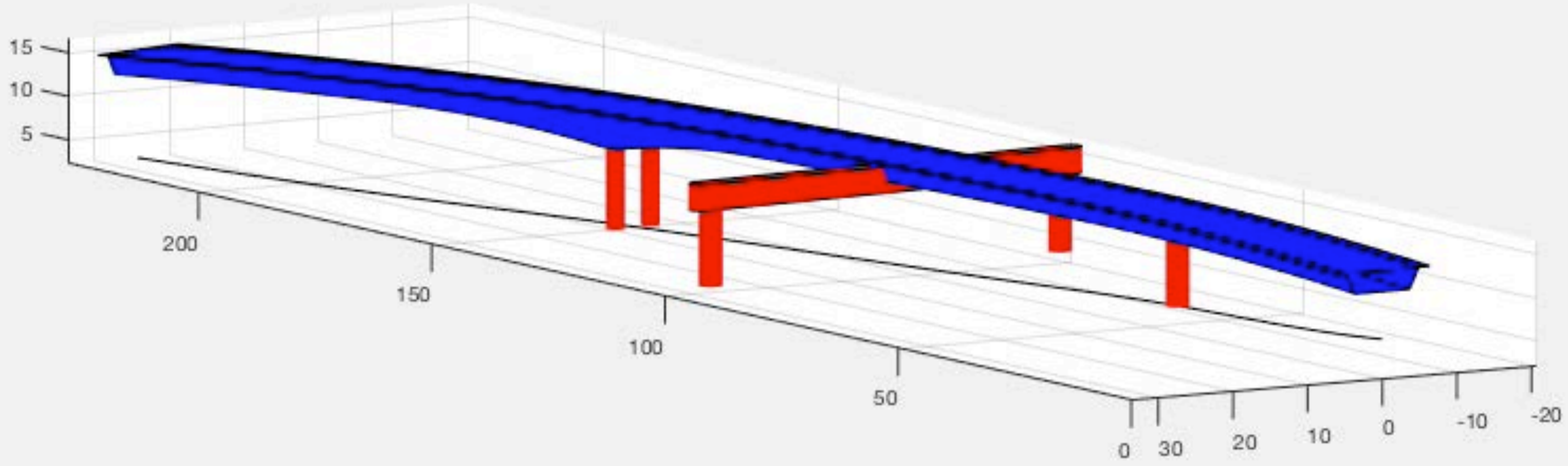


UCLA

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

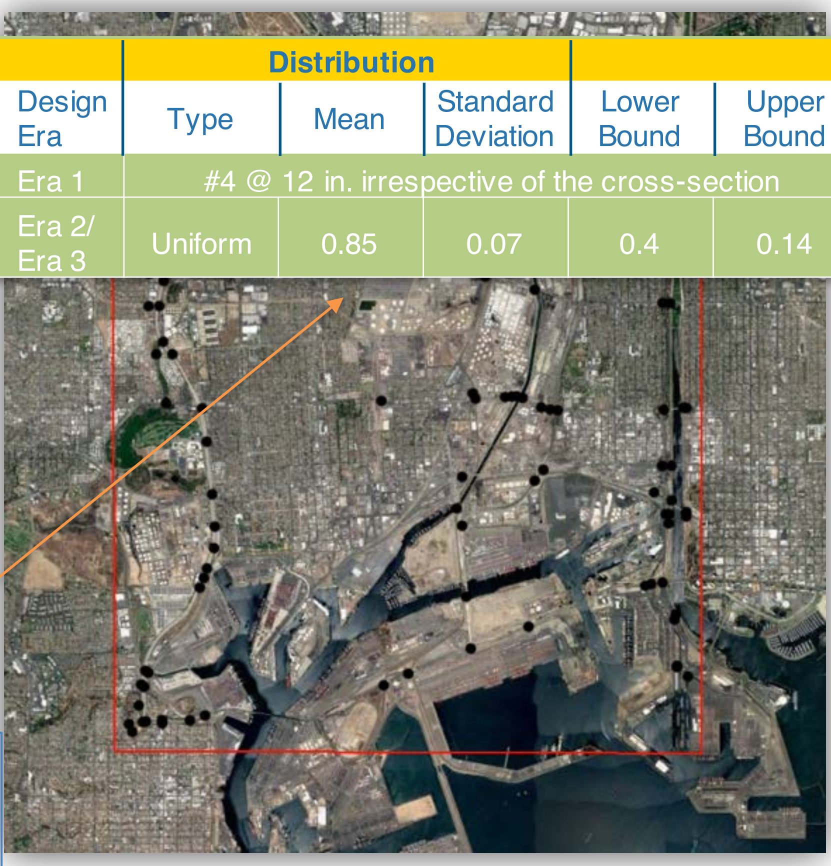
- 5x6 miles rectangular region containing all critical bridges connecting to Port of Los Angeles
- ROI contains 95 bridges
- 62 bridges built <1970 and have not been retrofitted

Bridge Model Inventory

- Geometries generated with UCLA tool from street view + satellite images
- Structural properties are assigned probabilistically based on a Georg 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

mean values here

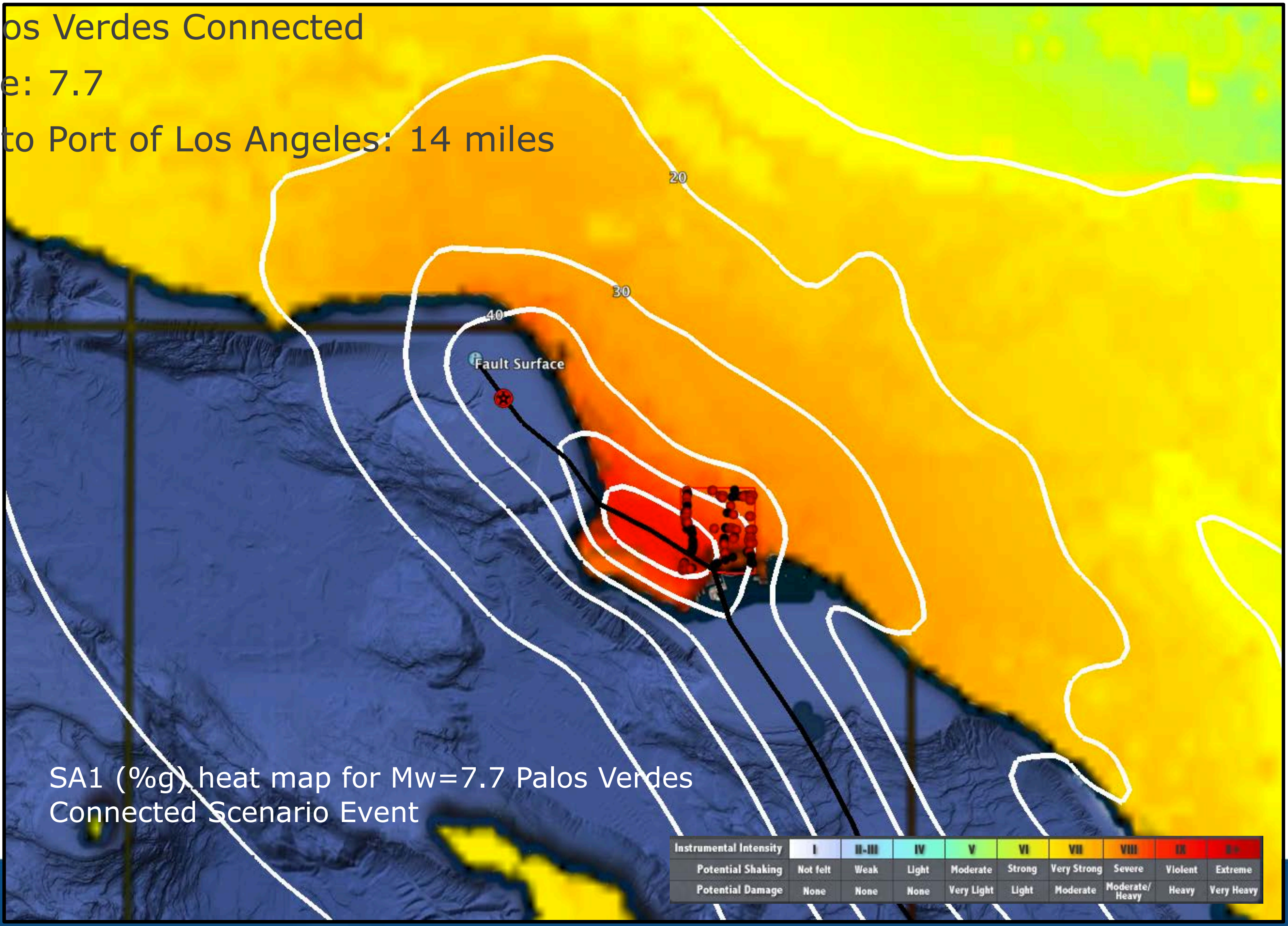
	Distribution				
Design Era	Type	Mean	Standard Deviation	Lower Bound	Upper Bound
Era 1	#4 @ 12 in. irrespective of the cross-section				
Era 2/ Era 3	Uniform	0.85	0.07	0.4	0.14



* Depends on design era (Era 1: pre-1971/pre-ductile, Era 2: 1971-1990/early ductile, Era 3: post-1990/modern ductile

Scenario Event

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

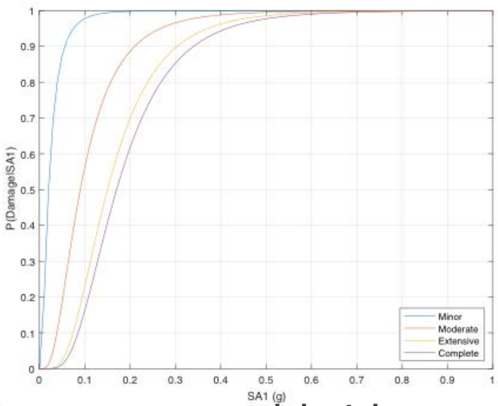


SA1 (%g) heat map for Mw=7.7 Palos Verdes Connected Scenario Event

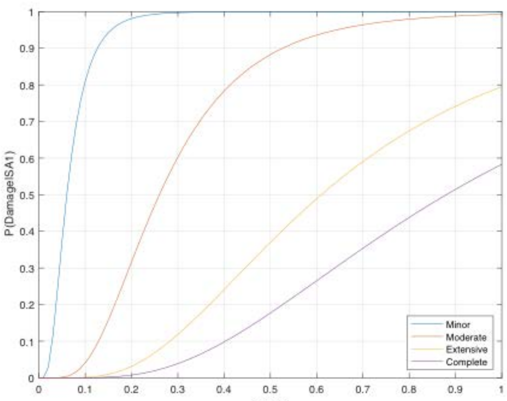
UCLA

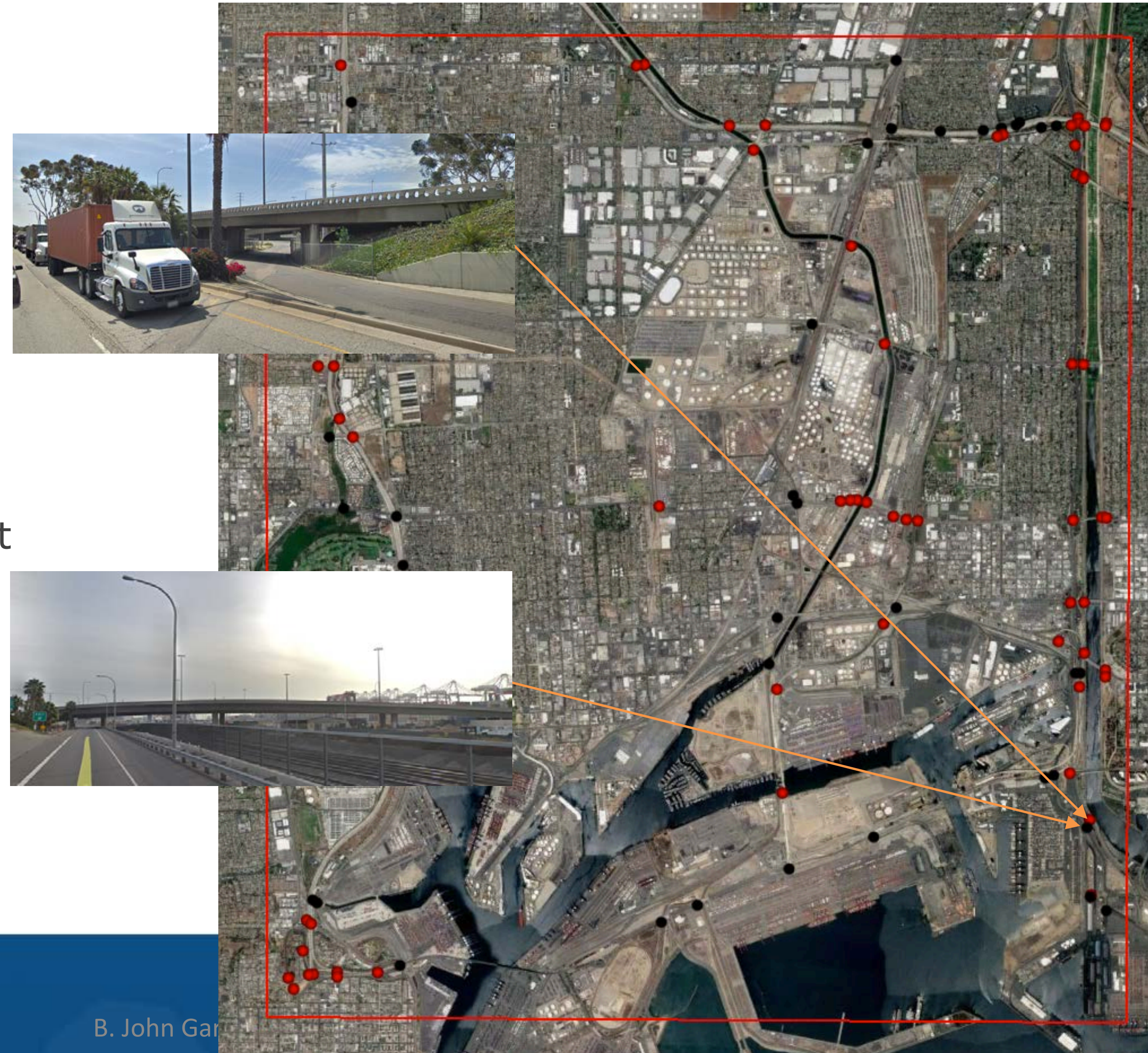
Bridge Closures

3-span bridge
YB=1970, seat abutment



5-span curved bridge
YB=1997, seat abutment



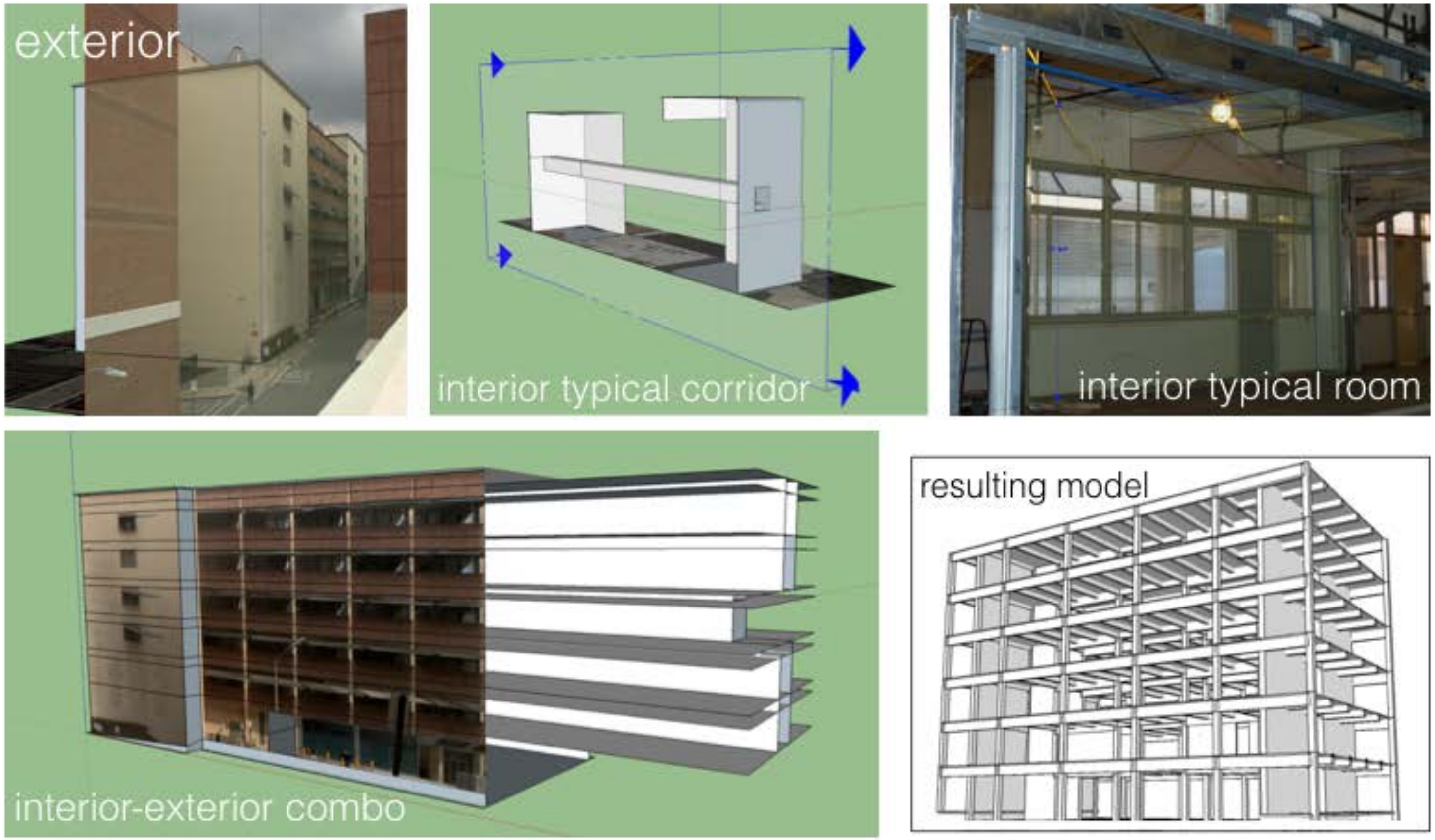


Quo Vadis?

- 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?

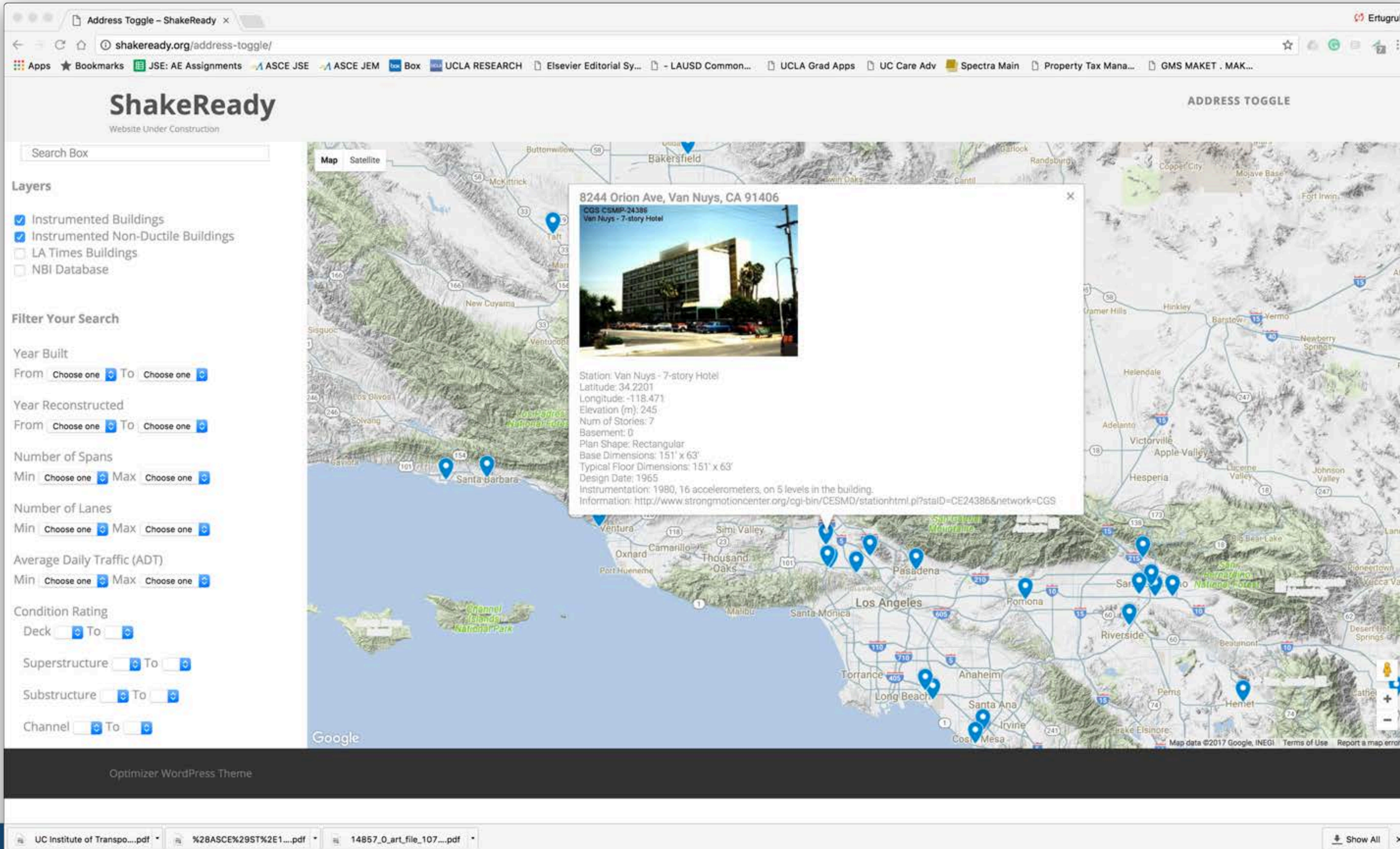
Building models from image data



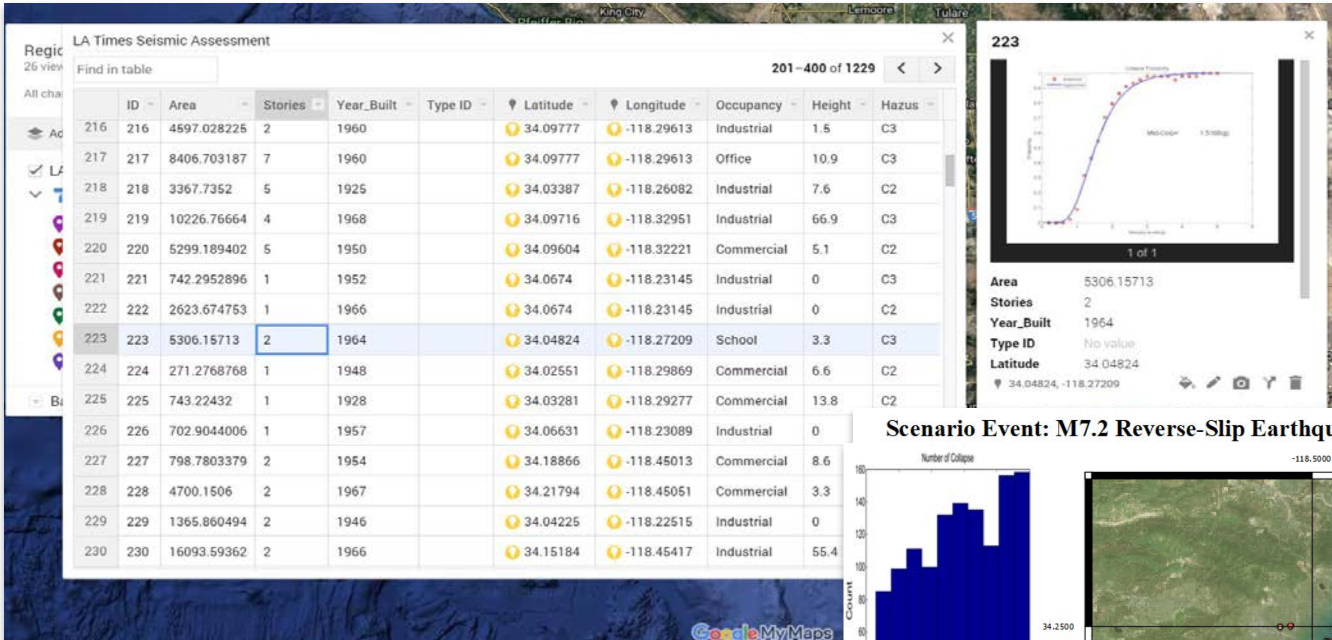
ShakeReady

a user interface under development

Building inventories



Non-ductile reinforced concrete buildings under a scenario event


LA Times Seismic Assessment

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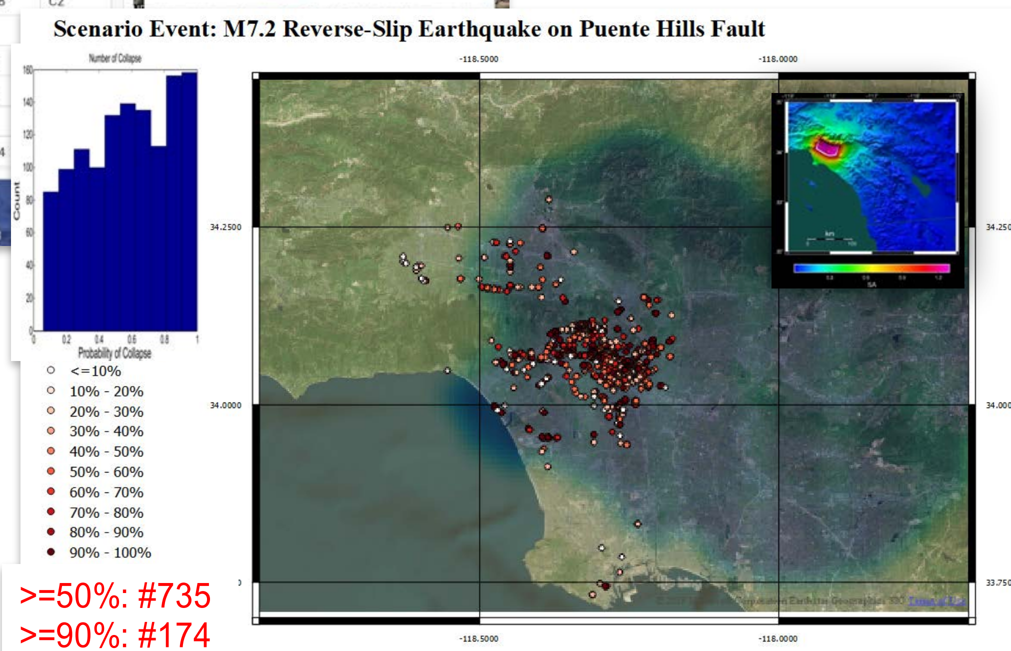
	ID	Area	Stories	Year_Built	Type ID	Latitude	Longitude	Occupancy	Height	Hazus
216	216	4597.028225	2	1960		34.09777	-118.29613	Industrial	1.5	C3
217	217	8406.703187	7	1960		34.09777	-118.29613	Office	10.9	C3
218	218	3367.7352	5	1925		34.03387	-118.26082	Industrial	7.6	C2
219	219	10226.76664	4	1968		34.09716	-118.32951	Industrial	66.9	C3
220	220	5299.189402	5	1950		34.09604	-118.32221	Commercial	5.1	C2
221	221	742.2952896	1	1952		34.0674	-118.23145	Industrial	0	C3
222	222	2623.674753	1	1966		34.0674	-118.23145	Industrial	0	C2
223	223	5306.15713	2	1964		34.04824	-118.27209	School	3.3	C3
224	224	271.2768768	1	1948		34.02551	-118.29869	Commercial	6.6	C2
225	225	743.22432	1	1928		34.03281	-118.29277	Commercial	13.8	C2
226	226	702.9044006	1	1957		34.06631	-118.23089	Industrial	0	
227	227	798.7803379	2	1954		34.18866	-118.45013	Commercial	8.6	
228	228	4700.1506	2	1967		34.21794	-118.45051	Commercial	3.3	
229	229	1365.860494	2	1946		34.04225	-118.22515	Industrial	0	
230	230	16093.59362	2	1966		34.15184	-118.45417	Industrial	55.4	

223

1 of 1

Area	5306.15713
Stories	2
Year_Built	1964
Type ID	No value
Latitude	34.04824

34.04824, -118.27209



>=50%: #735
>=90%: #174

thank you!

etacir@ucla.edu