A Vision for Regional PBSA

work in progress

by
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Outline

- Motivation and Objectives
- Vision and Scope
- Details of Envisioned Components
- Preliminary Work
- Future Work

Motivation and Objectives

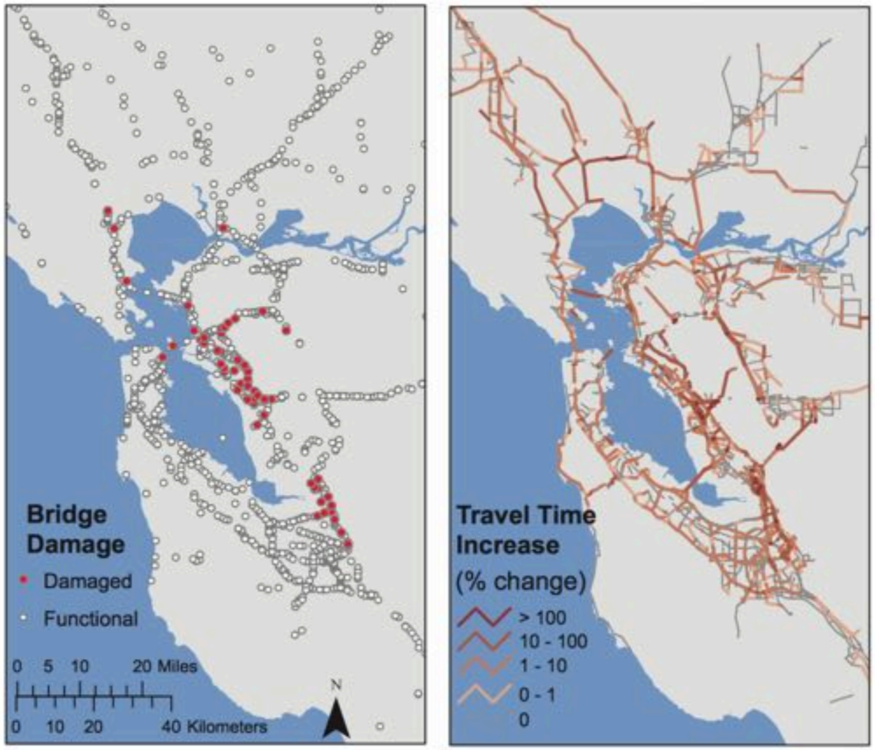
Why regional assessment?

- 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 to metadata to models
  - Heterogeneous sample population (requires automation + crowdsourcing)
  - Access permission to data is not automatic (requires harvesting—legally—and co-opting)
  - Processing would break records for civils (requires *large* computational resources)
- Models to decision variables
  - Heterogeneous analysis tools (OpenSees, OpenSHA, PACT)
  - New tech needs to be brought in (data analytics, machine-learning, inference)

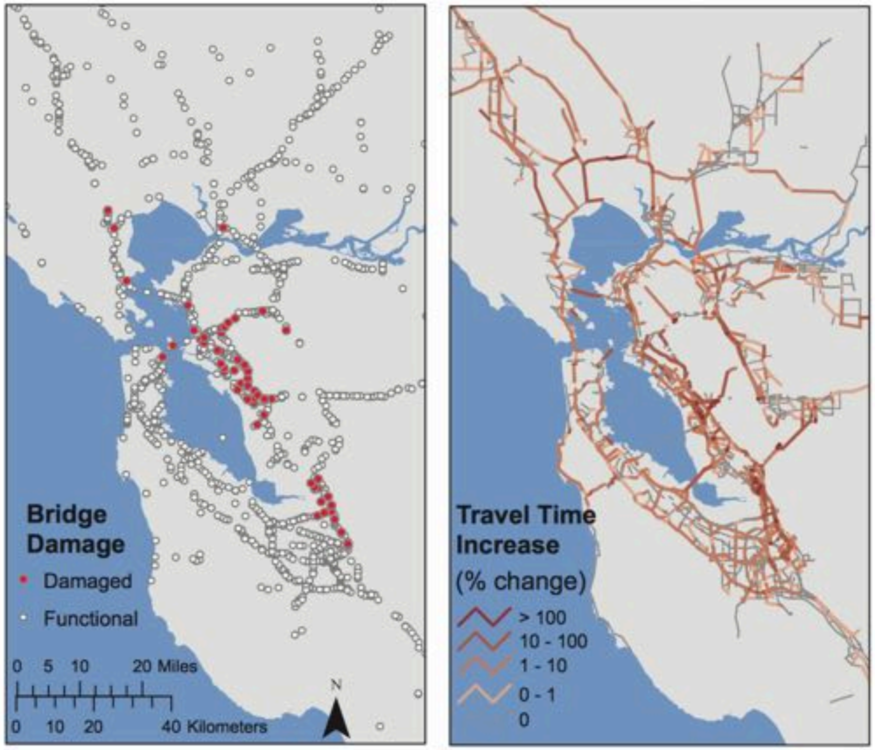
Motivation and Objectives



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

Developing a (semi-) automated program that can **develop image-based structural models** and has the capability of evaluating seismic vulnerability of complex transportation infrastructure networks and the consequent network-level/economic effects.

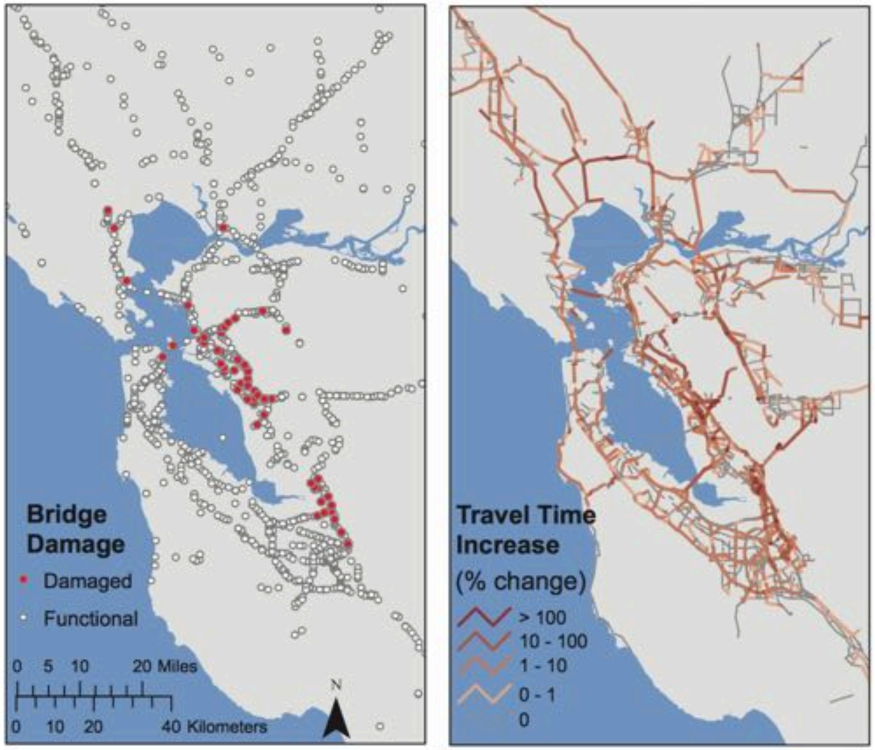
Motivation and Objectives



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

Existing predictive computational tools and IT capabilities allow *unprecedented granularity* in seismic risk and loss assessment

Motivation and Objectives



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

Hasn't been done before (at site-, structure-, and scenario-specific granularity)

Vision and Scope

Vision and Scope

Key Ingredients

- (Semi-)automated generation of high-fidelity models

  Images, NBI, Caltrans as-built plans, Crowd-sourcing

- Site-specific ground motion suites

  OpenSHA, PEER NGA-West 2 Ground Motion Database

- Cloud-based analysis and post-processing

  OpenSees on Amazon Cloud Services (or similar)

- Loss estimation

  PACT (or similar)

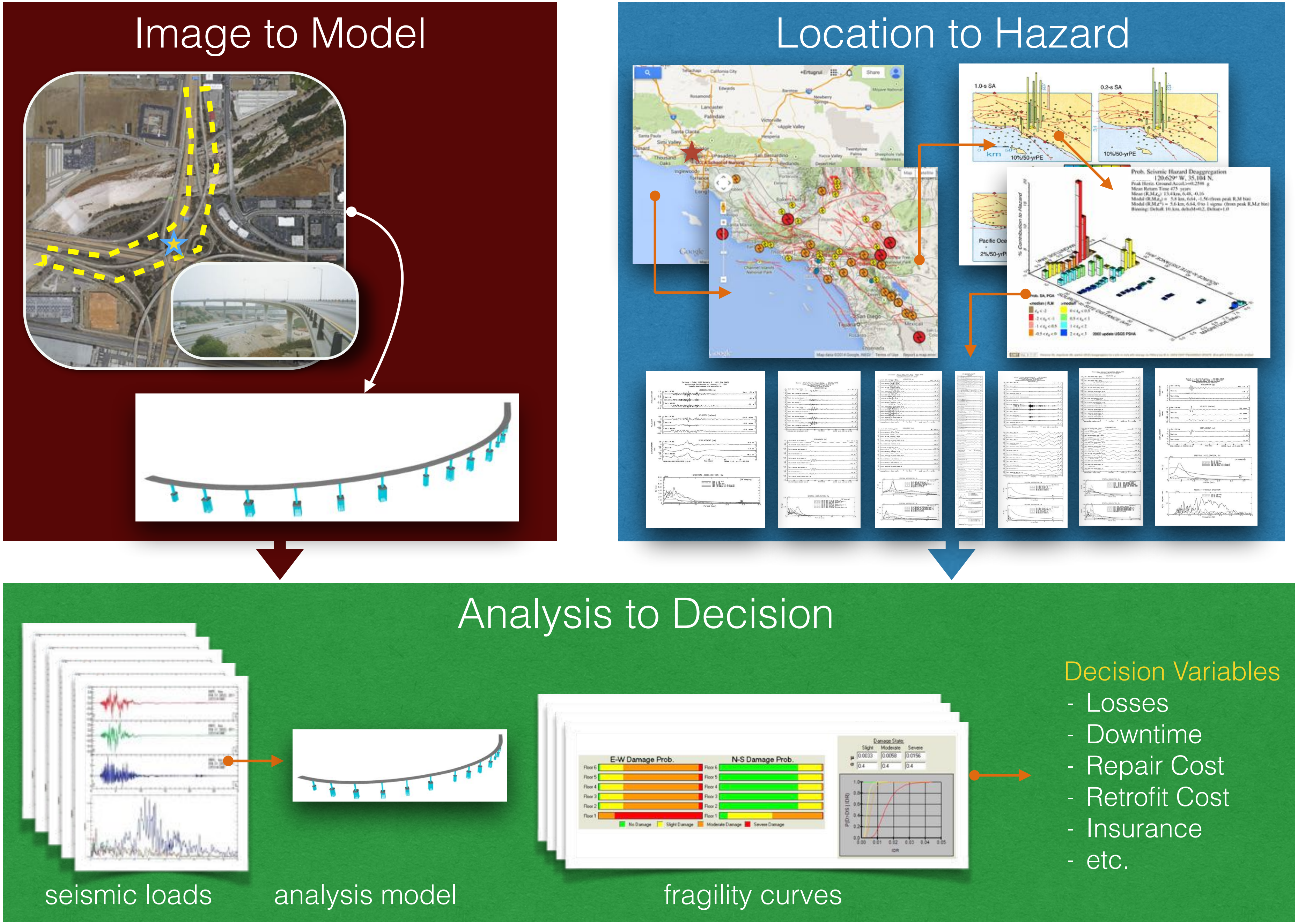


Image to Model
Location to Hazard
Analysis to Decision
Decision Variables
- Losses
- Downtime
- Repair Cost
- Retrofit Cost
- Insurance
- etc.
seismic loads
analysis model
fragility curves

Details of Envisioned Components

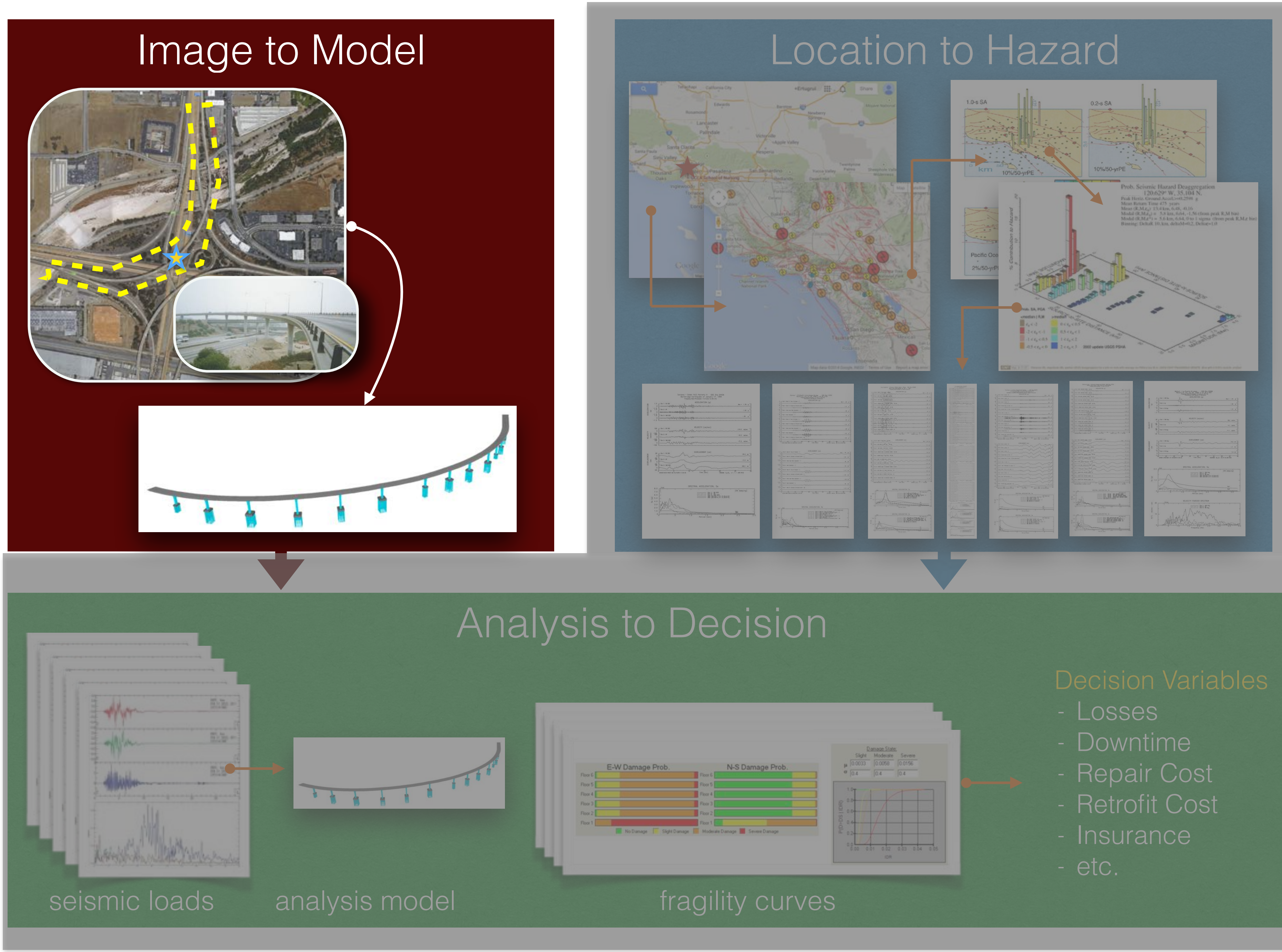


Image to Model
Location to Hazard
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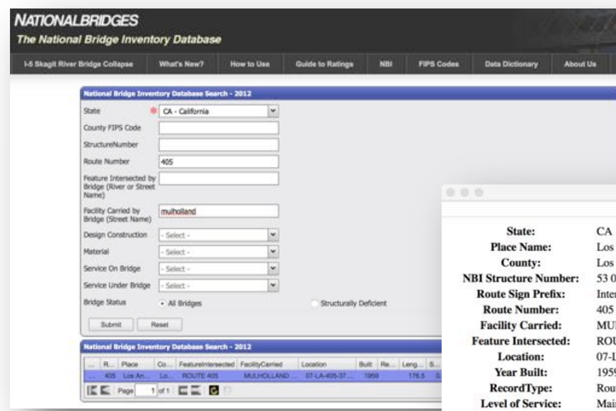
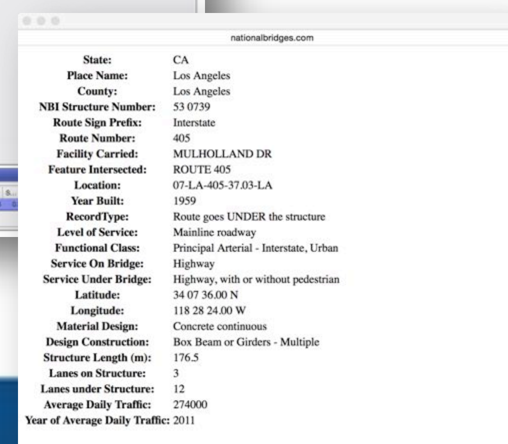
- Retrofit Cost
- Insurance
- etc.
E-W Damage Prob.
N-S Damage Prob.
seismic loads
analysis model
fragility curves

Where will the data come from?

Databases

- National Bridge Inventory
  - compiled by the *Federal Highway Administration (FHWA)*
  - provides metadata on "*all*" bridges and tunnels in the U.S.
  - its primary intent is to book-keep bridge conditions
    - provides a 0-9 scale rating on components (superstructure, deck, culvert, etc.)
  - it can be interrogated online
    - Year built, const. type, skew angle, material, length, num. lanes, avg. daily traffic, etc.





nationalbridges.com

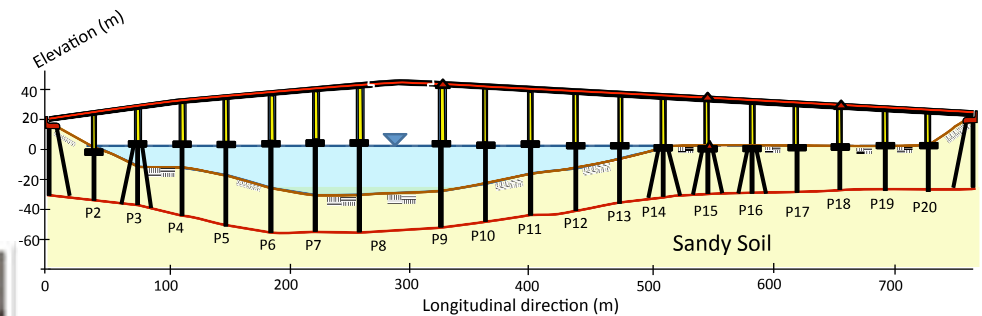
State:	CA
Place Name:	Los Angeles
County:	Los Angeles
NBI Structure Number:	53 0739
Route Sign Prefix:	Interstate
Route Number:	405
Facility Carried:	MULHOLLAND DR
Feature Intersected:	ROUTE 405
Location:	07-LA-405-37.03-LA
Year Built:	1959
RecordType:	Route goes UNDER the structure
Level of Service:	Mainline roadway
Functional Class:	Principal Arterial - Interstate, Urban
Service On Bridge:	Highway
Service Under Bridge:	Highway, with or without pedestrian
Latitude:	34 07 36.00 N
Longitude:	118 28 24.00 W
Material Design:	Concrete continuous
Design Construction:	Box Beam or Girders - Multiple
Structure Length (m):	176.5
Lanes on Structure:	3
Lanes under Structure:	12
Average Daily Traffic:	274000
Year of Average Daily Traffic:	2011

Where will the data come from?

Databases

- Caltrans Bridge Database
  - compiled by the *California Department of Transportation (Caltrans)*
  - provides *all* details of bridges (including site conditions and foundation configurations)
  - it *cannot* be interrogated online (permission required by Caltrans)

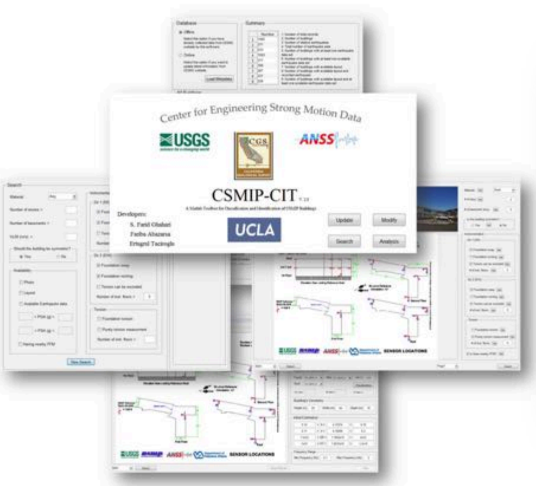
Number of Spans	20
Plan Shape	Straight
Total Length	2507' (764.1m)
Width of Deck	34' (10.4m)
Construction Year	1971
Instrumentation Year	1996
Seismic Retrofit	2006



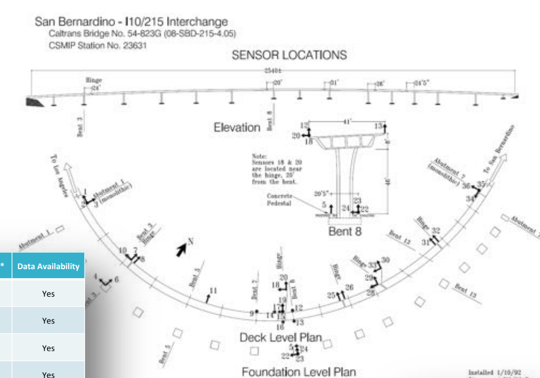
Where will the data come from?

Databases

- California Strong Motion Instrumentation Database
  - Maintained by Caltrans and *California Geological Survey (CGS)*
  - provides *most* details of 72 bridges in CA (including site conditions and foundation configurations)
  - it *can* be interrogated online
  - contains bridge response data from past earthquake (model validation)



Event	Date	Magnitude	Source Location		Ep. Dist.(km)	PGA (g)*	PSA (g)**	Data Availability
			Lat.(N)	Long.(W)				
Landers	06/28/92	7.3 ML	34.22	116.43	81.3	0.180	0.820	Yes
Big Bear	06/28/92	6.5 ML	34.20	116.83	45.9	0.110	1.020	Yes
Northridge	01/17/94	6.4 ML	34.21	118.54	115.9	0.130	0.470	Yes
Big Bear City	02/22/03	5.4 ML	34.31	116.85	49.4	0.023	0.053	Yes
Yucaipa	06/16/05	4.9 ML	34.06	117.1	26.7	0.135	0.244	Yes
Chio Hills	07/29/08	5.4 Mw	33.95	117.77	45.0	0.110	0.165	Yes
San Bernardino	01/08/09	4.5 ML	34.11	117.30	4.7	0.144	0.173	Yes
Calexico	04/04/10	7.2 Mw	32.26	115.29	274.3	0.032	0.072	Yes
Borrego Springs	01/07/10	5.4 ML	33.42	116.49	103.5	0.029	0.088	Yes



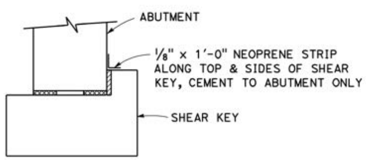
No. of Spans	16
Plan Shape	curved
Total Length	2540' (774.2m)
Width of Deck	41' (10.4m)
Construction Date	1966
Instrumentation Year	1992
Retrofit Year	1991
Bridge Channels	34 Channels
Free-field Channels	3 Channels

Where will the data come from?

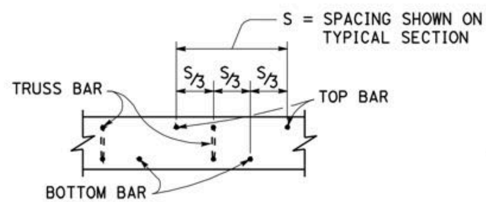
Guideline Documents

- Caltrans Standard Plans

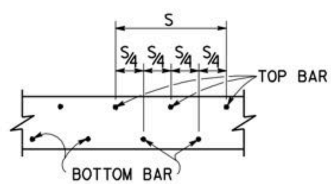
  allows determination of many metadata elements (e.g., abutment seat length, shear-key reinforcement, foundation configuration, etc.)



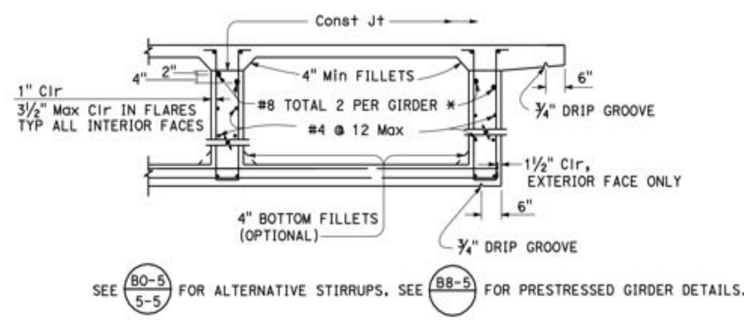
BRIDGE DETAIL 1-6
SHEAR KEY JOINT PROTECTION



BRIDGE DETAIL 5-10



BRIDGE DETAIL 5-11
TRANSVERSE DECK REINFORCEMENT
SPACING DIAGRAMS



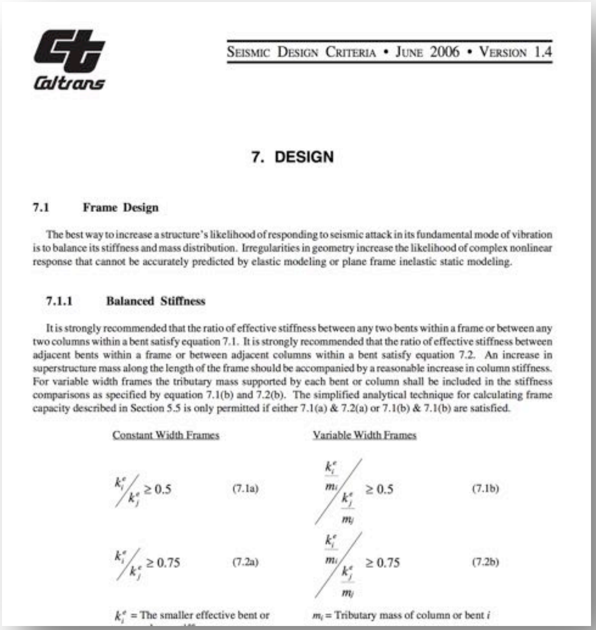
TYPICAL BOX GIRDER DETAILS
DETAIL B-1

Where will the data come from?

Guideline Documents

- Caltrans Seismic Design Criteria Manual

  provides era-specific information on component and system design



Seismic Design Criteria • June 2006 • Version 1.4

7. DESIGN

7.1 Frame Design

The best way to increase a structure's likelihood of responding to seismic attack in its fundamental mode of vibration is to balance its stiffness and mass distribution. Irregularities in geometry increase the likelihood of complex nonlinear response that cannot be accurately predicted by elastic modeling or plane frame inelastic static modeling.

7.1.1 Balanced Stiffness

It is strongly recommended that the ratio of effective stiffness between any two bents within a frame or between any two columns within a bent satisfy equation 7.1. It is strongly recommended that the ratio of effective stiffness between adjacent bents within a frame or between adjacent columns within a bent satisfy equation 7.2. An increase in superstructure mass along the length of the frame should be accompanied by a reasonable increase in column stiffness. For variable width frames the tributary mass supported by each bent or column shall be included in the stiffness comparisons as specified by equation 7.1(b) and 7.2(b). The simplified analytical technique for calculating frame capacity described in Section 5.5 is only permitted if either 7.1(a) & 7.2(a) or 7.1(b) & 7.1(b) are satisfied.

Constant Width Frames

$$k_i^e / k_j^e \geq 0.5 \qquad (7.1a)$$

$$k_i^e / k_j^e \geq 0.75 \qquad (7.2a)$$

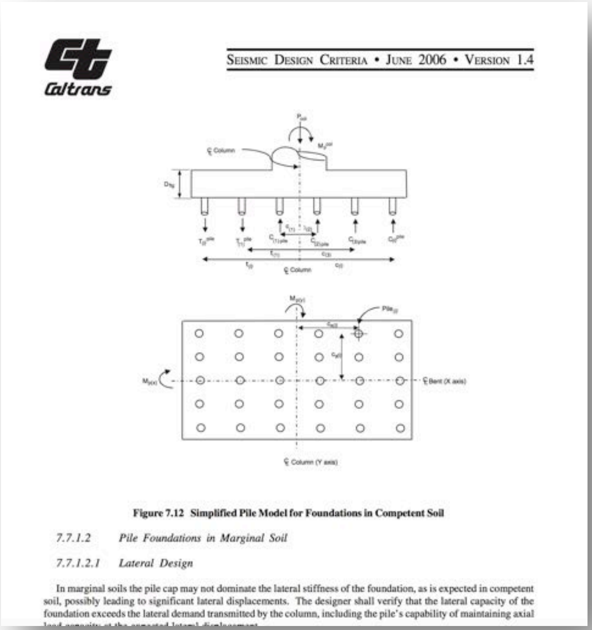
Variable Width Frames

$$\frac{k_i^e}{m_i} \Big/ \frac{k_j^e}{m_j} \geq 0.5 \qquad (7.1b)$$

$$\frac{k_i^e}{m_i} \Big/ \frac{k_j^e}{m_j} \geq 0.75 \qquad (7.2b)$$

k_i^e = The smaller effective bent or

m_i = Tributary mass of column or bent i



Seismic Design Criteria • June 2006 • Version 1.4

Figure 7.12 Simplified Pile Model for Foundations in Competent Soil

7.7.1.2 Pile Foundations in Marginal Soil

7.7.1.2.1 Lateral Design

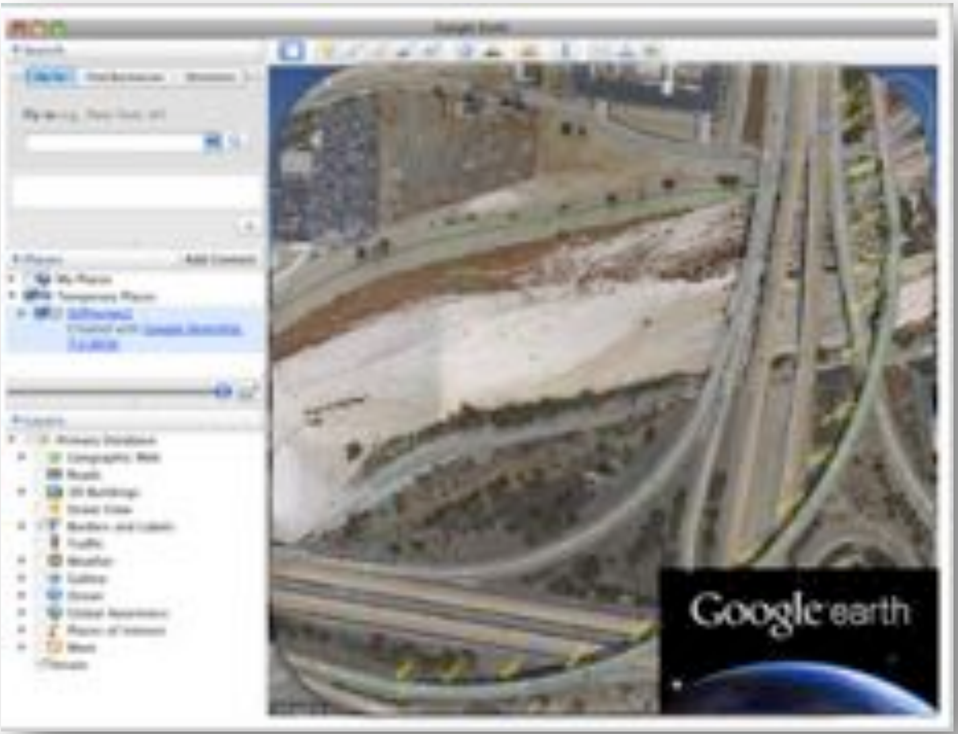
In marginal soils the pile cap may not dominate the lateral stiffness of the foundation, as is expected in competent soil, possibly leading to significant lateral displacements. The designer shall verify that the lateral capacity of the foundation exceeds the lateral demand transmitted by the column, including the pile's capability of maintaining axial

Where will the data come from?

Internet Harvesting

- Google Maps/Earth, etc.

  can be interrogated online
  more on this later …

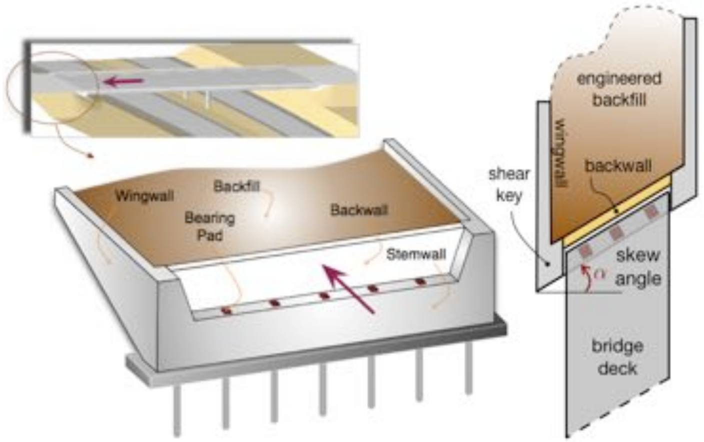


Where will the data come from?

Internet Harvesting

- Crowd Sourcing
  - uses human intelligence when algorithms are too difficult to devise
  - wikipedia-type consensus models can be built (contributors v. referees)

Typical Seat Abutment



UCLA

Image to Model

Detection of Bridge Locations

Read approximate bridge coordinates from NBI

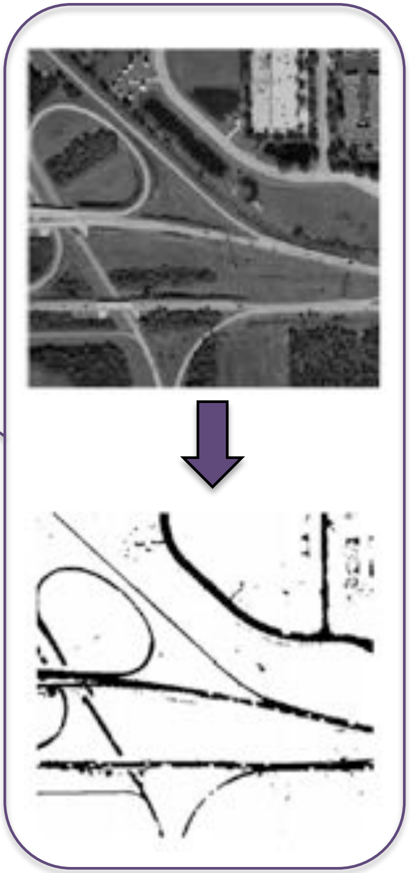
Extract satellite image of the location corresponding to approximate bridge coordinate using

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

Pick two random points on any detected continuous road line and pass coordinates of points into

Read inventory route information from NBI, then highlight the interested road line

Prompt for bridge beginning and end points from user



Segmented Road Extraction Results via Hybrid Method by Singh & Garg (2013)

Image to Model

Developing of Wireframe Bridge Models

1. Create a min. of 1000 sampling points between user-defined cord.
2. Get snapped points to road centerline curve
3. Determine ground elevations
4. Determine road elevations
5. Harvest Street View images at each virtual camera location
6. Identify bent locations using images
7. Establish wireframe bridge model

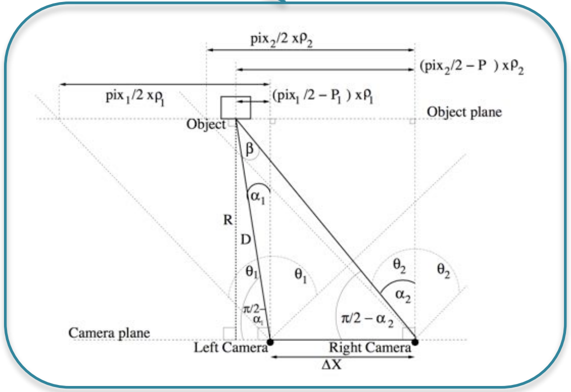


Image to Model

Determination of Deck Properties

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

+

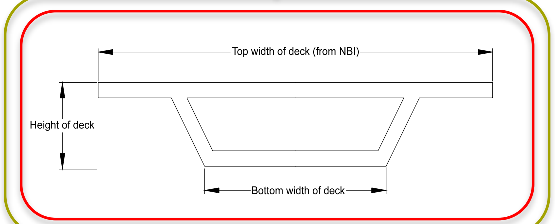
Determine desk superelevation profile by combining geometry info. and speed limit data

+

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

=

Estimate reinforcement detailing and corresponding structural properties



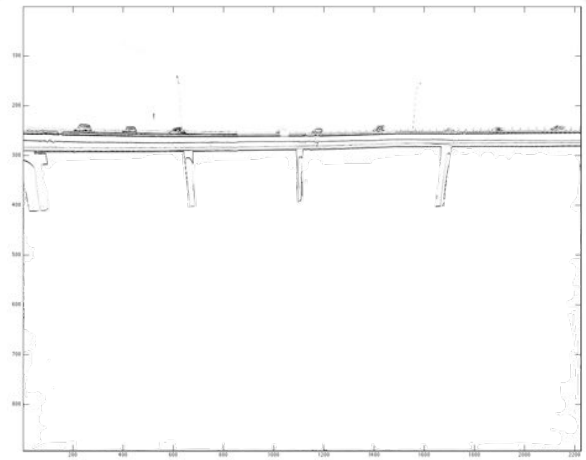
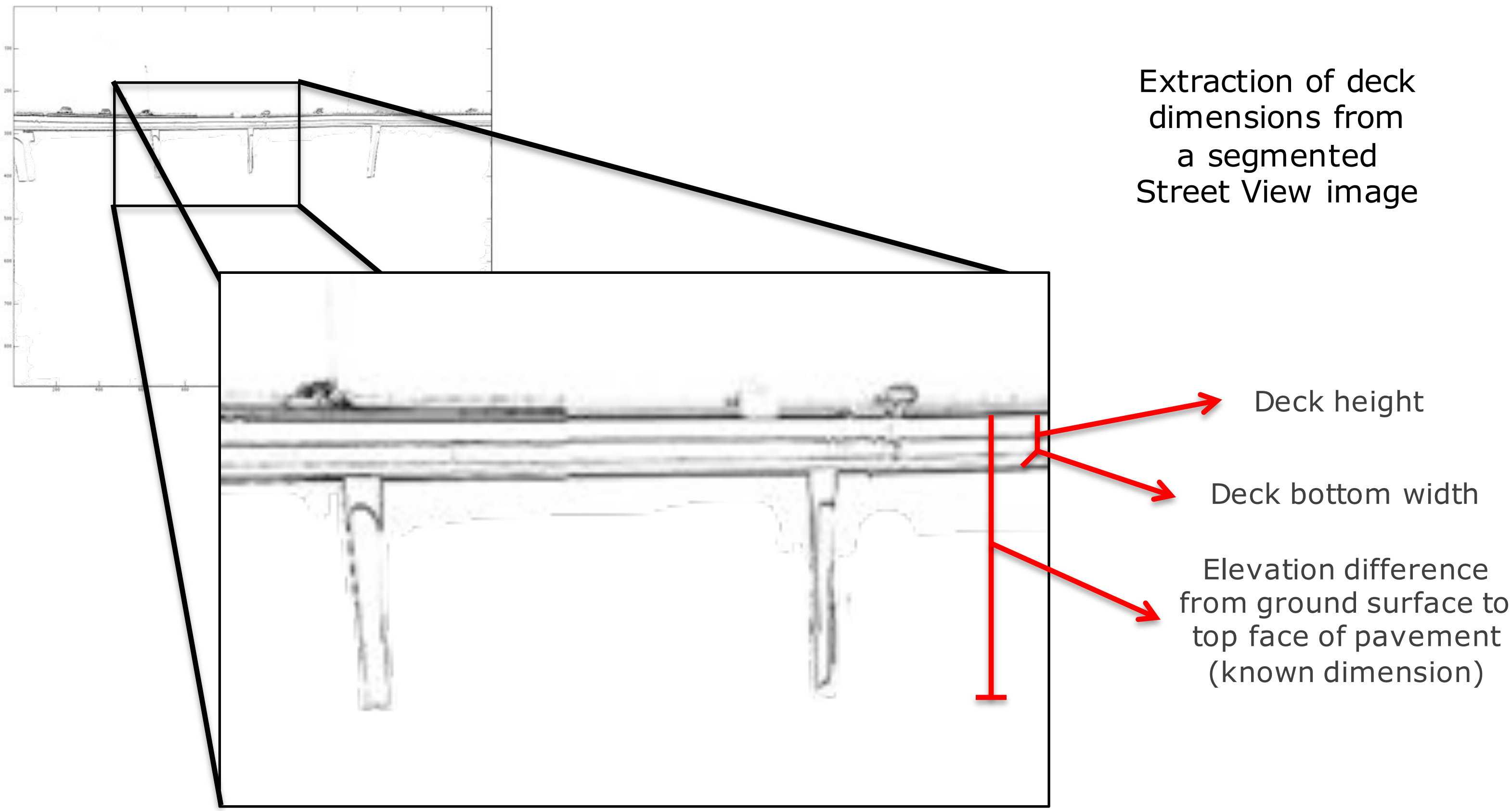


Image to Model

Determination of Deck Properties



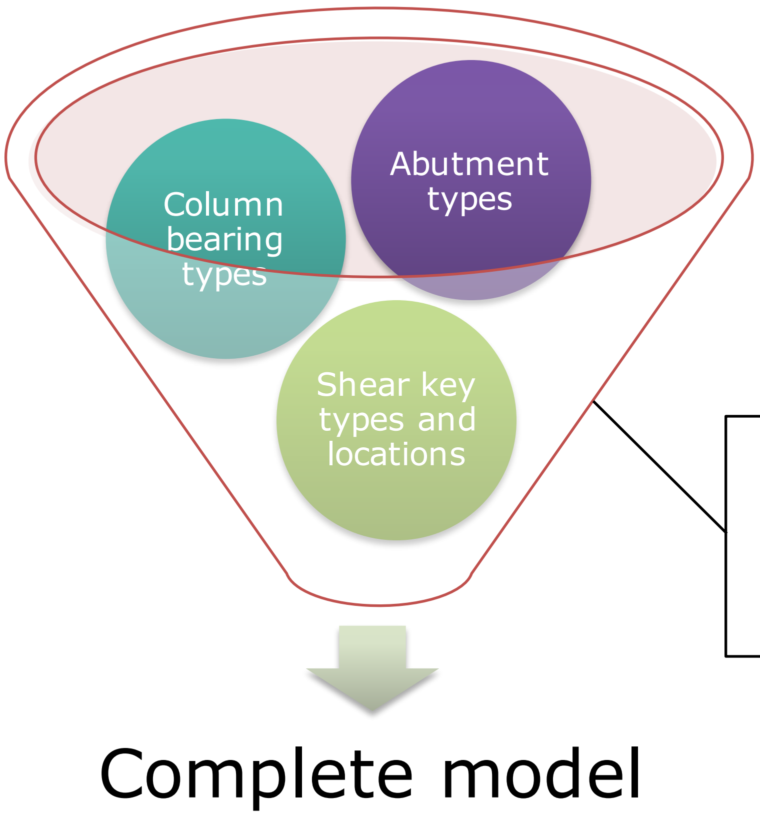
Extraction of deck dimensions from a segmented Street View image

Determination of Column Properties

1. Determine the column type based on the number of detected column edges
2. Sample column height and width at a number of levels
3. 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 crowdsourced data



Entire dataset distilled by utilizing information from Caltrans Bridge Standard Detail Sheets DGN files

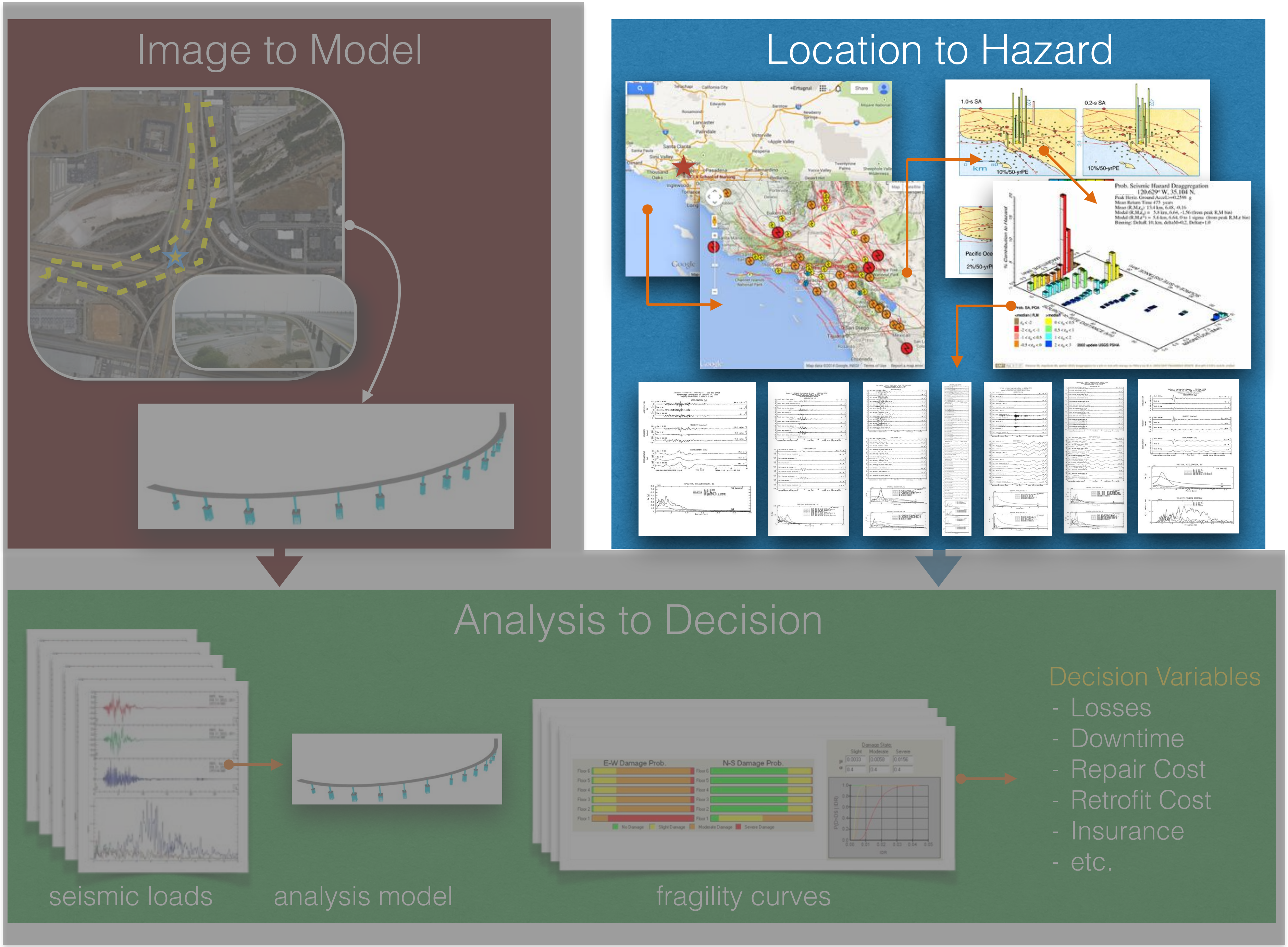
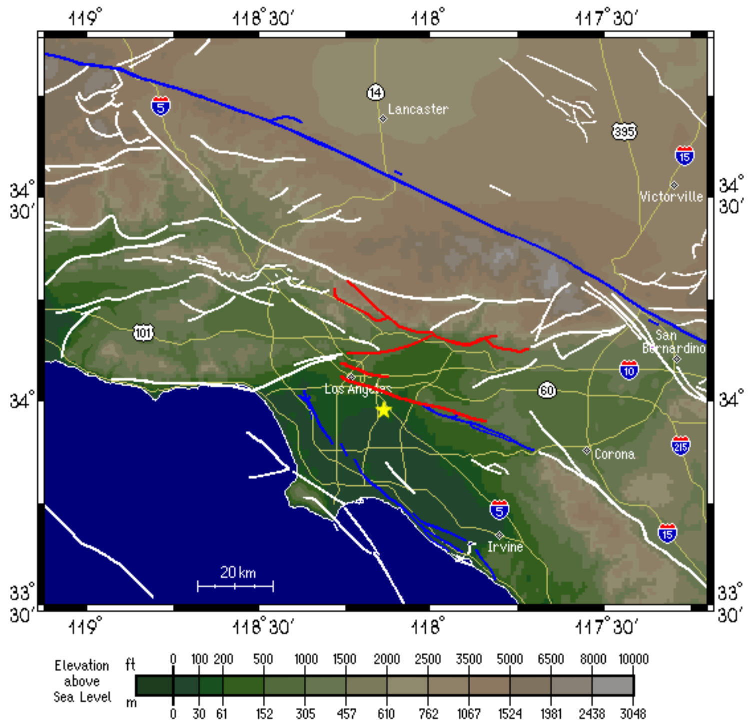


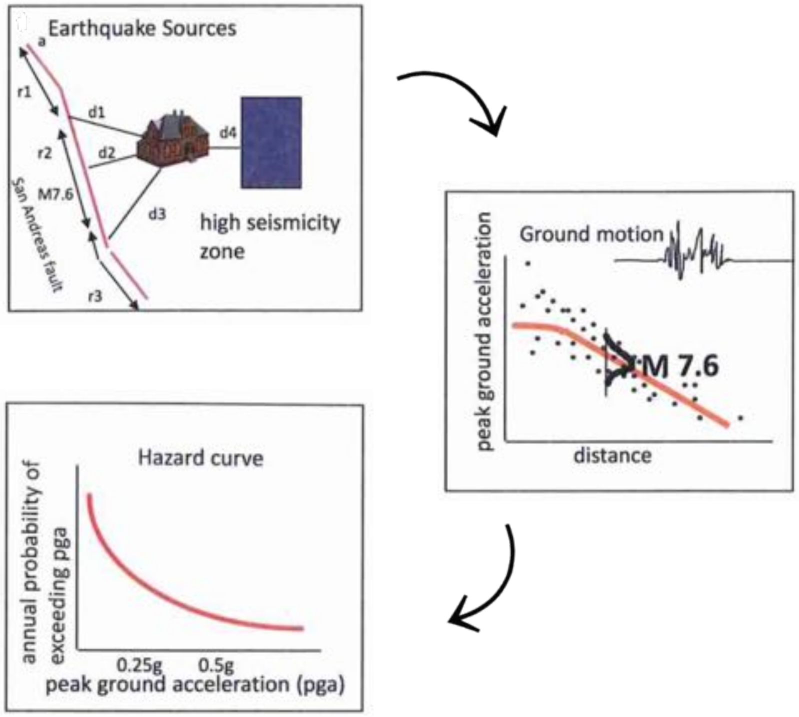
Image to Model
Location to Hazard
Analysis to Decision
seismic loads
analysis model
fragility curves
Decision Variables
- Losses
- Downtime
- Repair Cost
- Retrofit Cost
- Insurance
- etc.

Location to Hazard

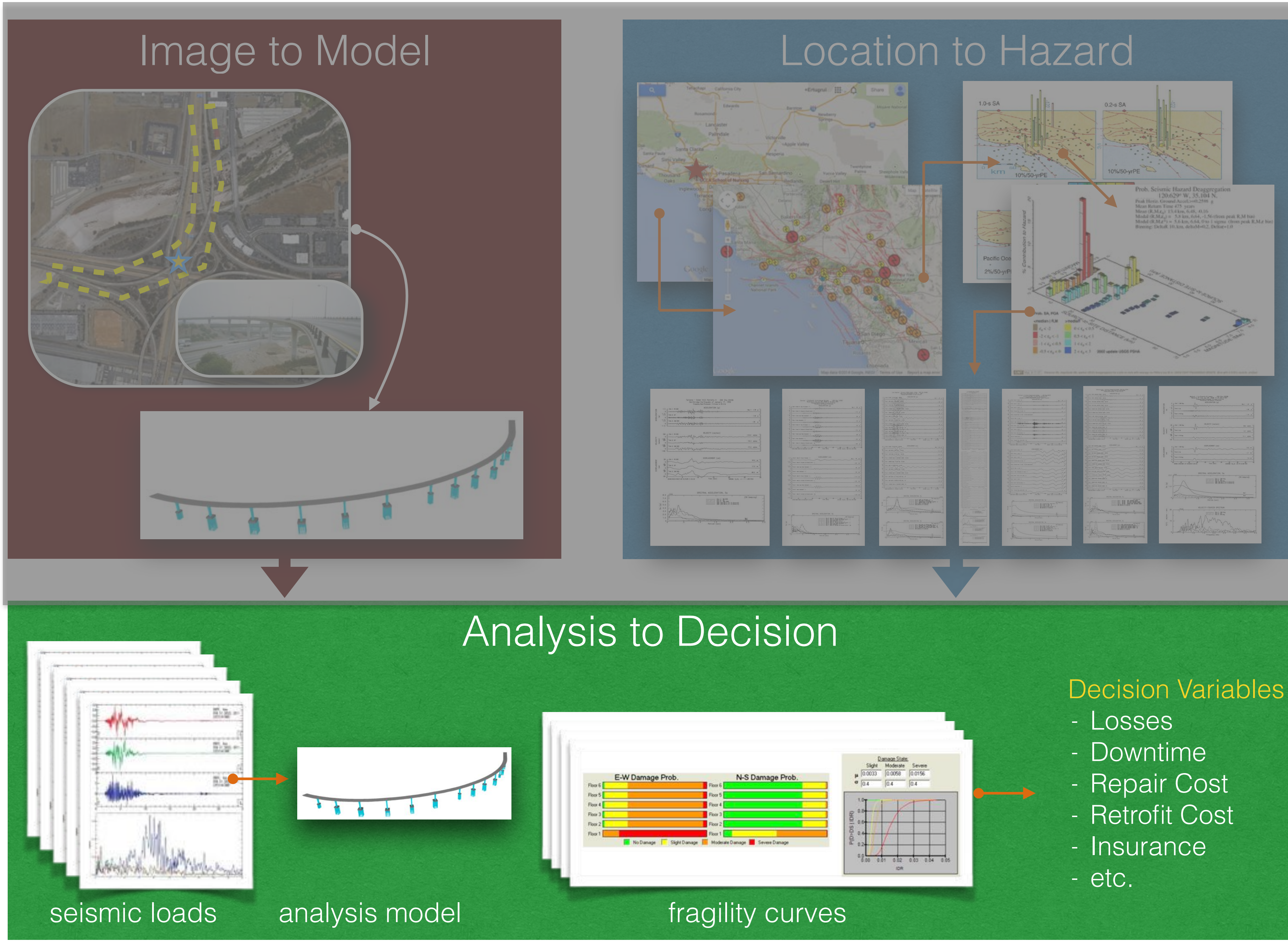
Probabilistic Seismic Hazard Assessment (PSHA)



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



Basic seismic hazard methodology (from Boore)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E-W Damage Prob.
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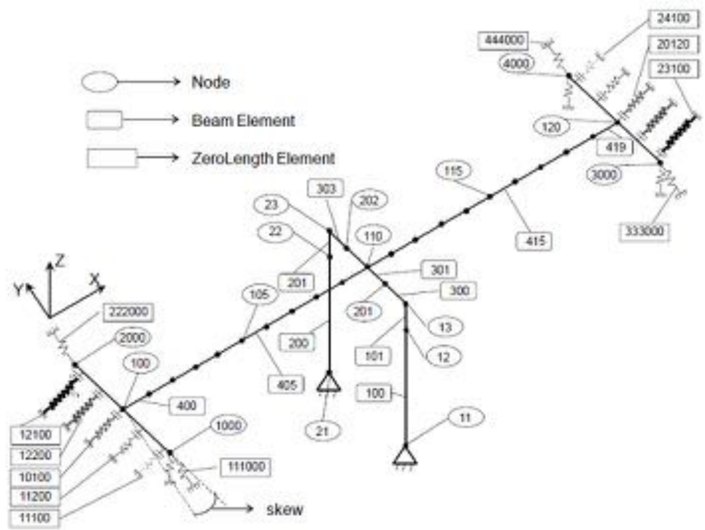
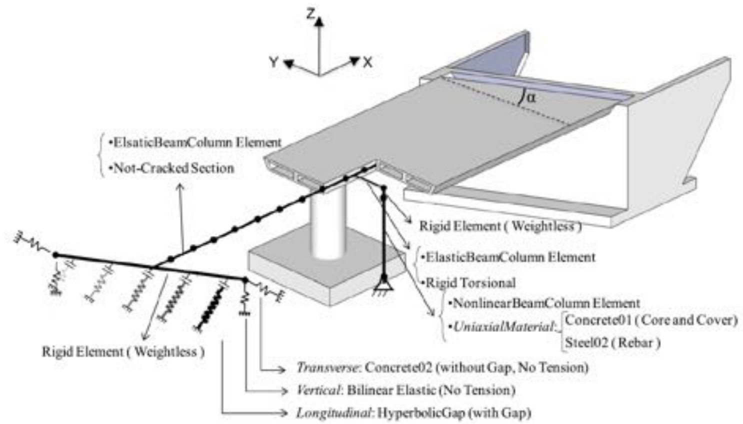
OpenSees Models

a brief overview

Building blocks of a bridge model





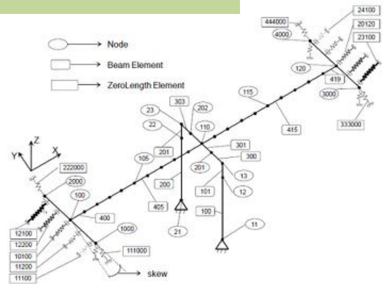
- Piles [Boulanger et al., 1999; Taciroglu et al., 2006; Khalili-Tehrani et al., 2014]
- Abutments [Stewart et al. 2007; Shamsabadi et al., 2010; Nojoumi et al., 2015]
- Shear keys [Mobasher et al., 2015; Omrani et al., 2015]
- In-span hinges [Trochalakis et al., 1997; Hube and Mosallam, 2008]
- Columns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

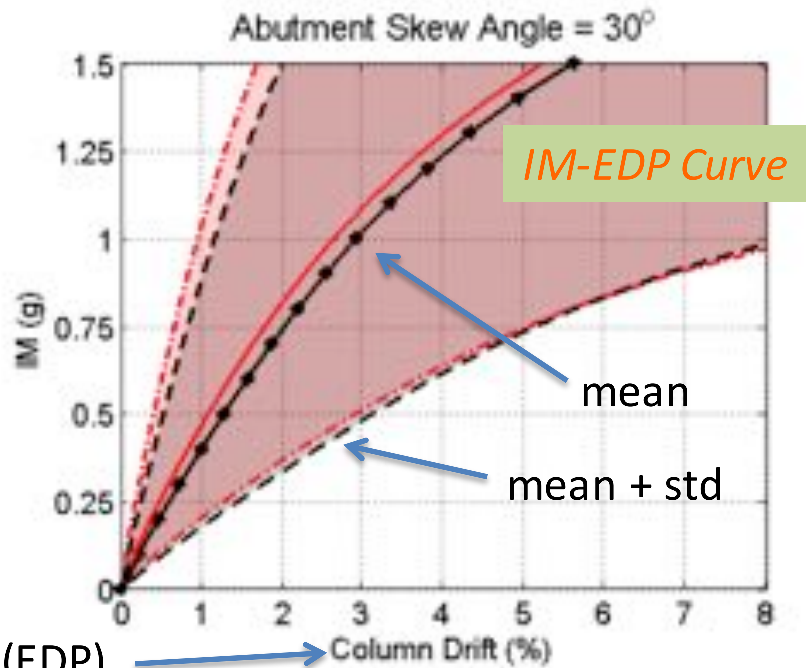
Detailed descriptions of component and system modeling are provided in

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 …

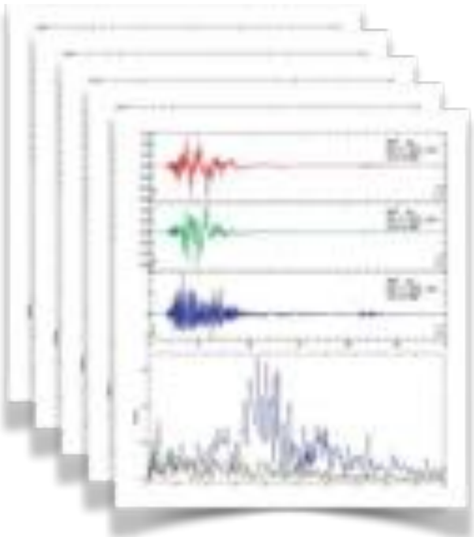
Monte Carlo (on cloud)

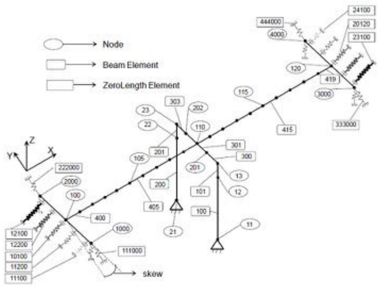




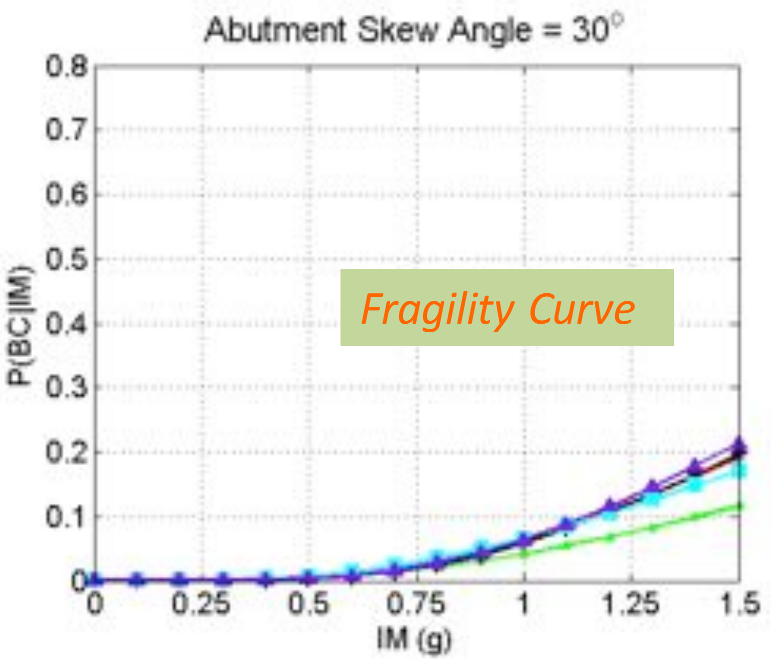
Engineering Demand Parameter (EDP)

Analysis yields …





Probability of Collapse
(*could be something else: e.g. Probably of Exceedance of a damage state for a particular component such as a shear key*)



Loss Estimation

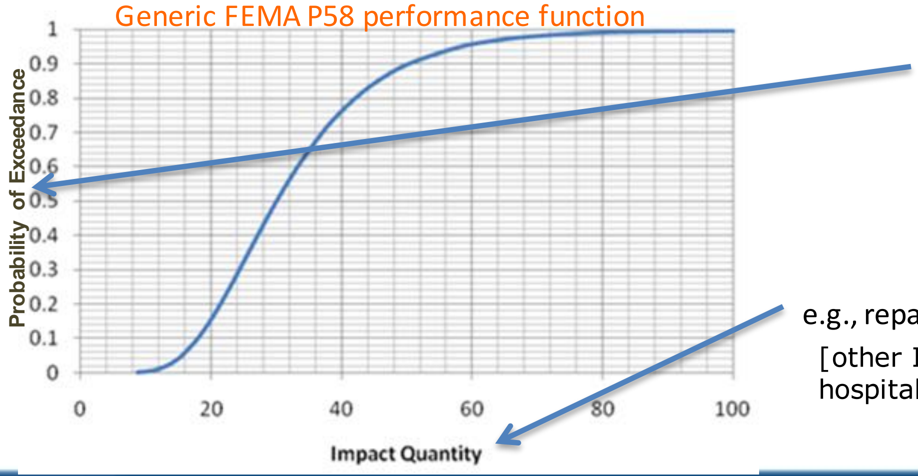
an open problem for bridges

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)*
  - *Outcome of the ATC-P58 project*
  - *Provides fragilities/performance-functions for structural and non-structural components, and systems*



e.g., PoE of floor acceleration value of 0.4*g*

e.g., repair costs to MRI machine on floor 2

[other IQ examples are repair time, injuries requiring hospitalization, deaths, hours to operability, etc.

EDP or Performance State to Loss & Downtime

- Similar capabilities in loss estimation for bridges are lacking

- The very few studies include
  - Estimation of post-event traffic capacity (Terzic)
  - Miller & Baker, 2013

- Our plans
  - Try to replicate the FEMA-P58 methodology for bridges
    - ➢ Develop *apps (tools)* for computing component fragilities (comp. fragilities enable rapid post-event assessment)
    - ➢ Compile repair/downtime data and statistics (Caltrans)
  - Devise methodologies for network impact and recovery analysis (UCLA Luskin)

Sample Applications

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

Coronado Bridge, San Diego CA

UCLA

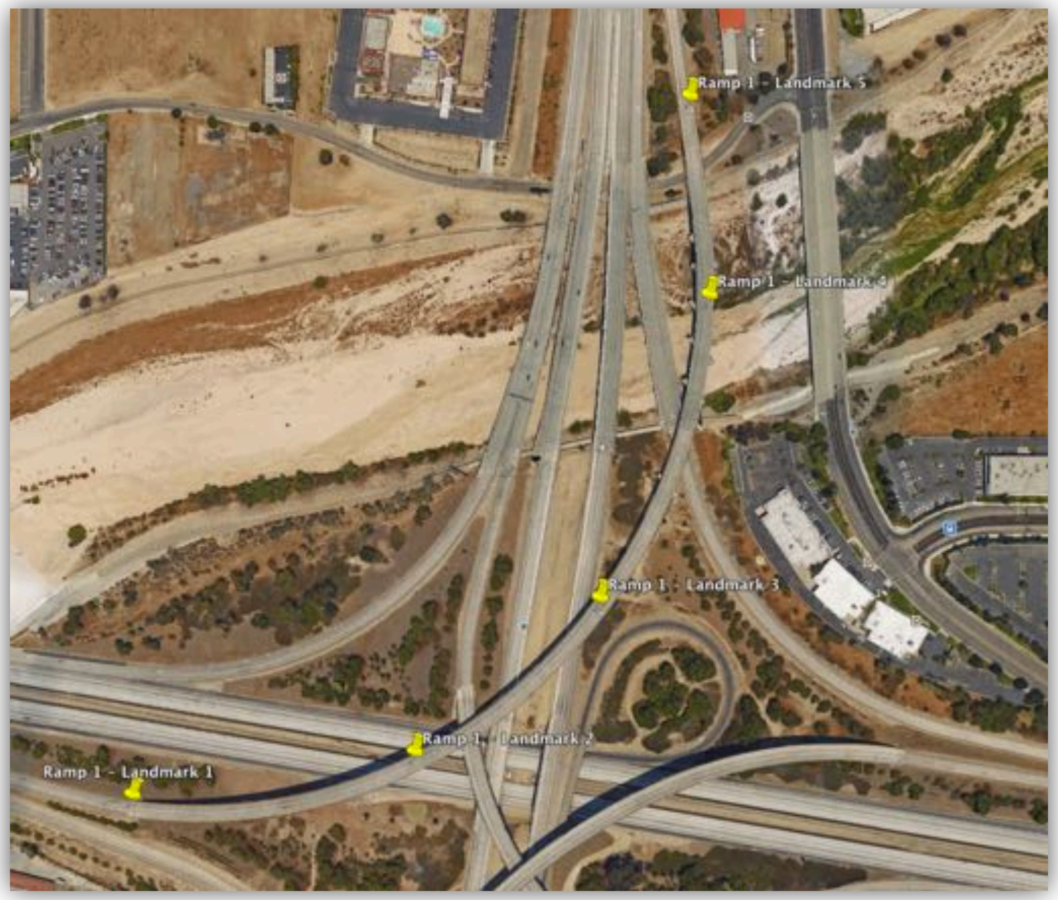
A Sample Application

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

UCLA

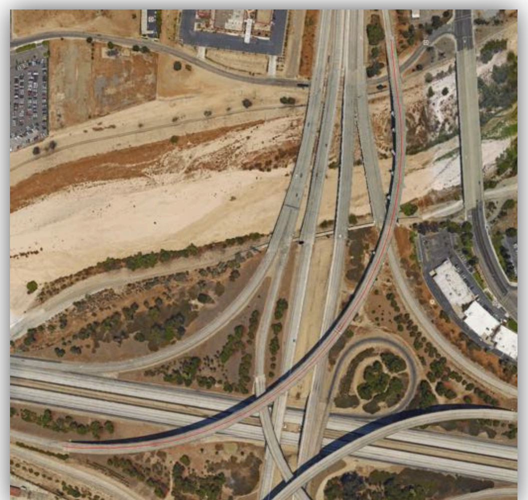
A Sample Application

Selection of random points on the bridge by the user



A Sample Application

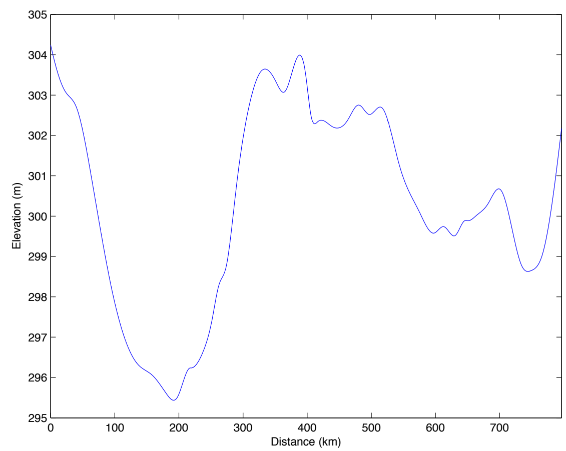
Initial processing of selected points by program



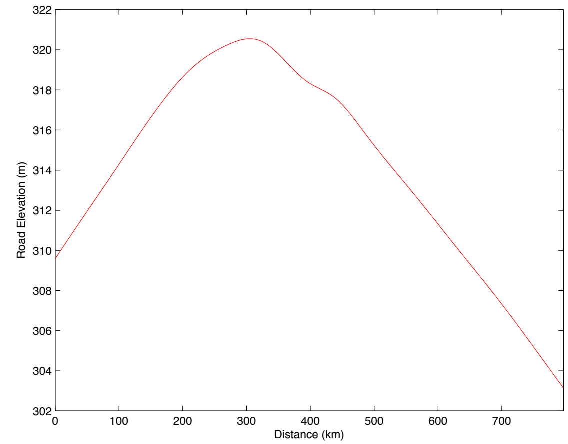
Calculation of bridge centerline curve

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

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



Determination of ground elevations



Determination of road elevations

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

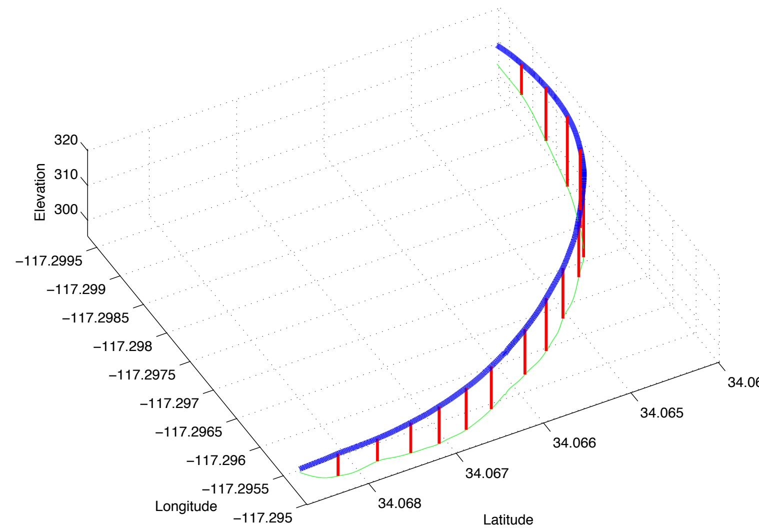
A Sample Application

Using of image processing to identify bent locations and developing of wireframe model

Identification of bent locations

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

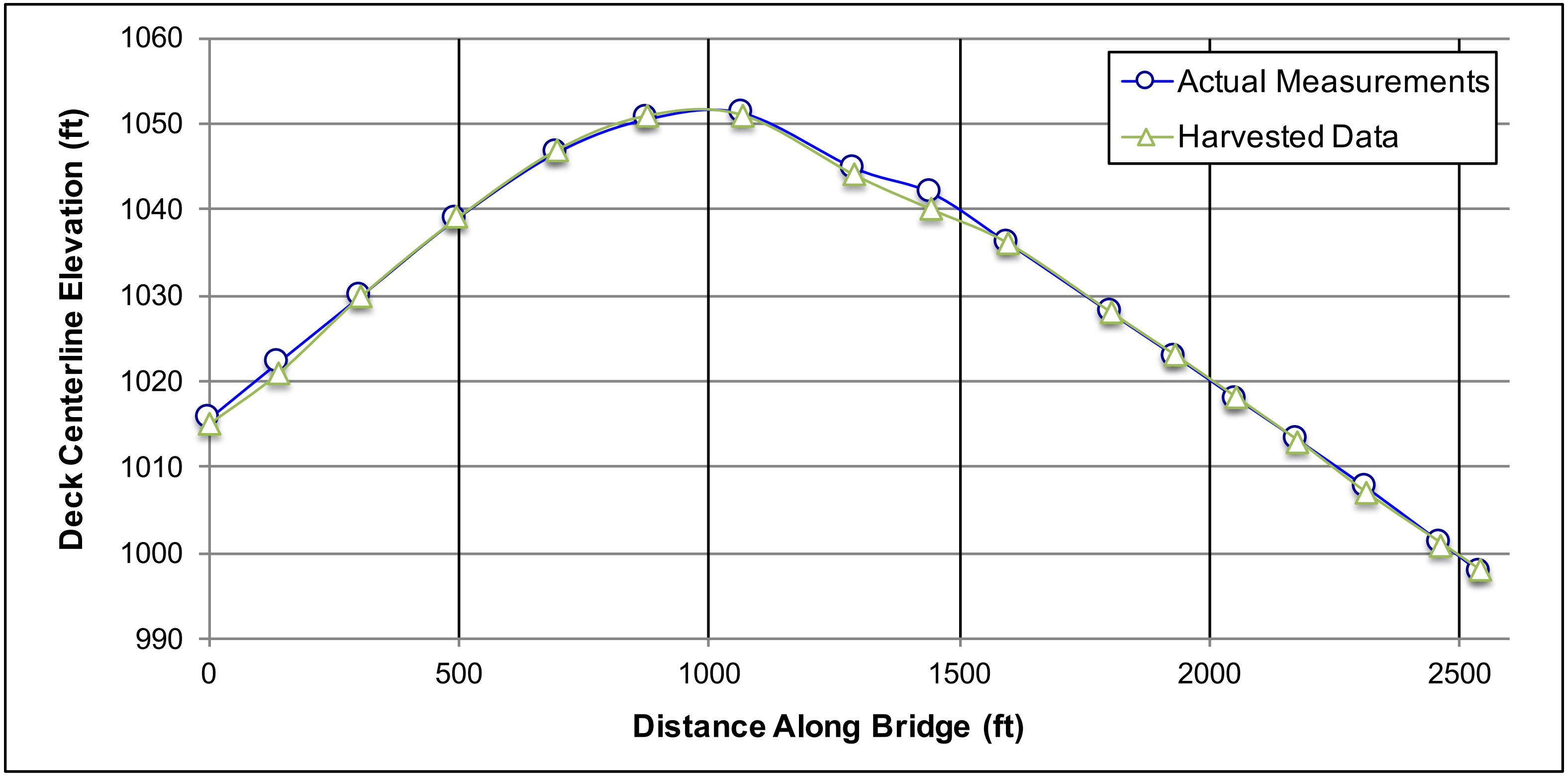
*Using ***UCLA*** automated image-based structural model development program via *Wireframe Model Builder Module*



Establishing of wireframe model

A Sample Application

Comparison of harvested data against information from as-built drawings

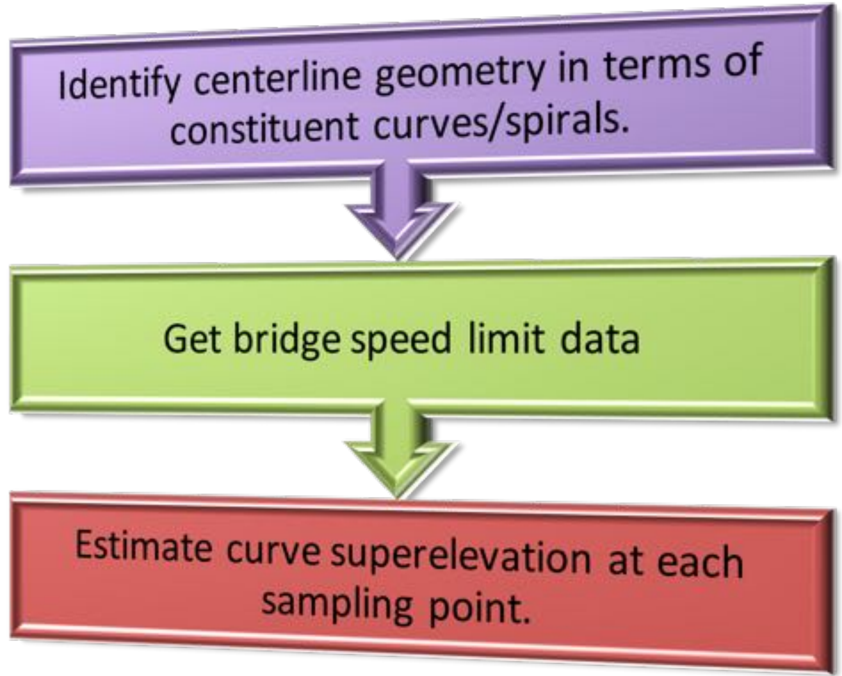


A Sample Application

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*

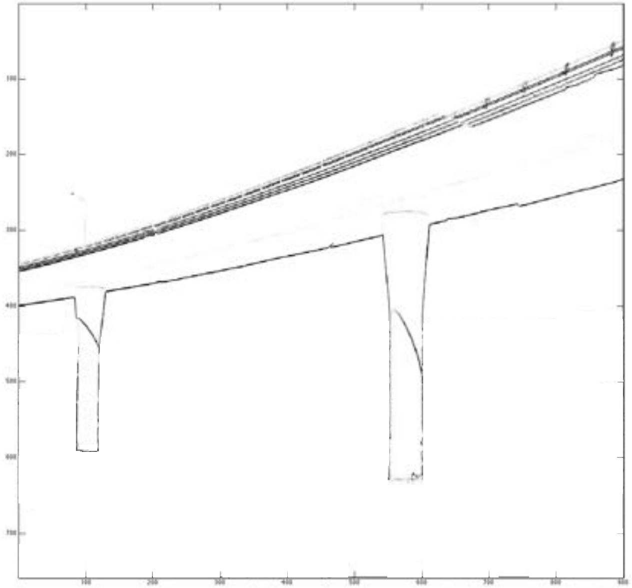


Basic methodology to determine curve superelevation profile

*A new module to detect deck superelevation information from images is under development and is expected to replace this program component.

A Sample Application

Determination of bridge column dimensions



Detection of column edges

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

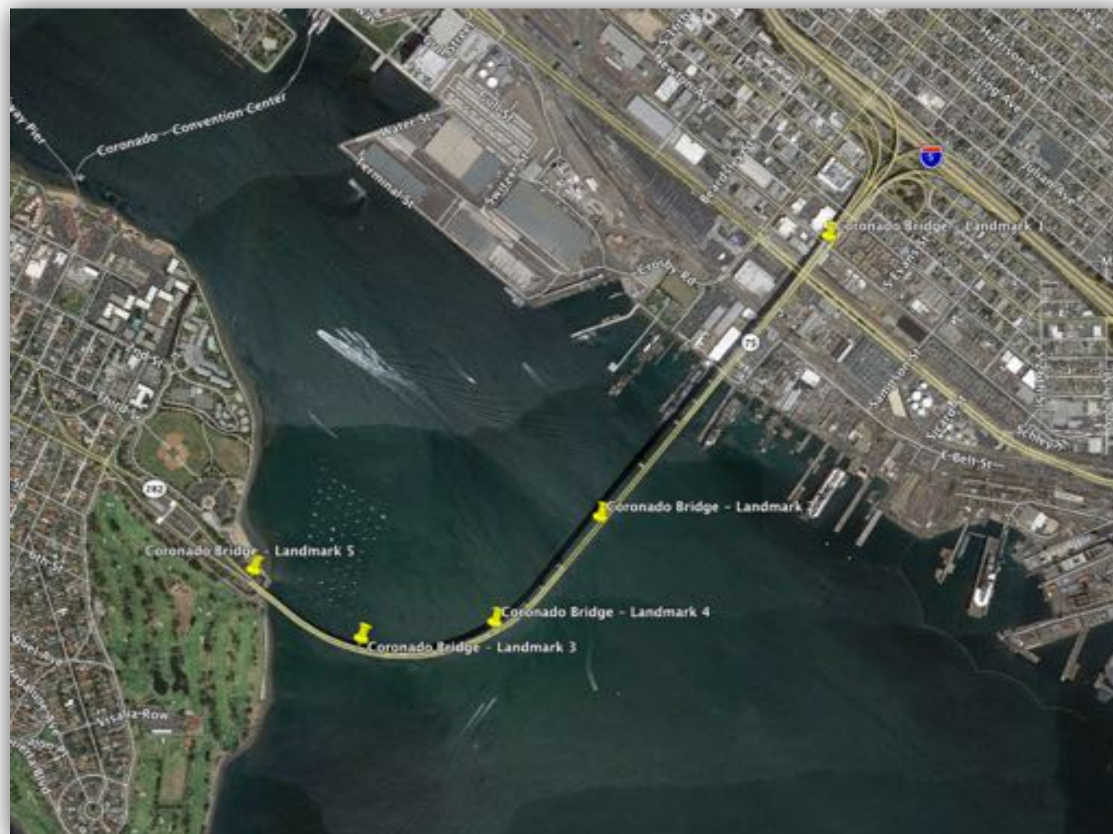
*Using ***UCLA*** automated image-based structural model development program via *Pixel Counter Module*

Determination of column dimensions

A Case Study: San Diego – Coronado Bridge

A Case Study: San Diego – Coronado Bridge

Selection of random points on the bridge by the user



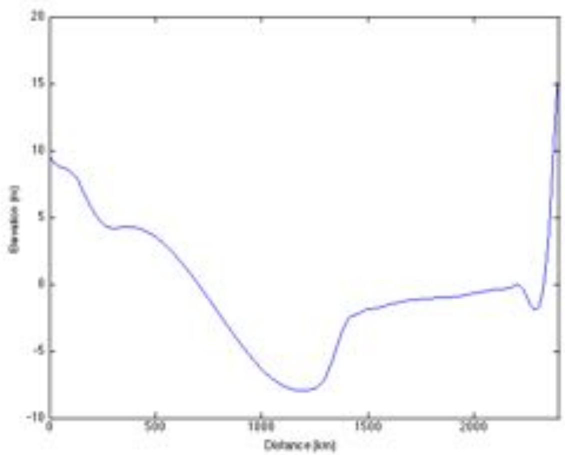
A Case Study: San Diego – Coronado Bridge

Initial processing of selected points by program

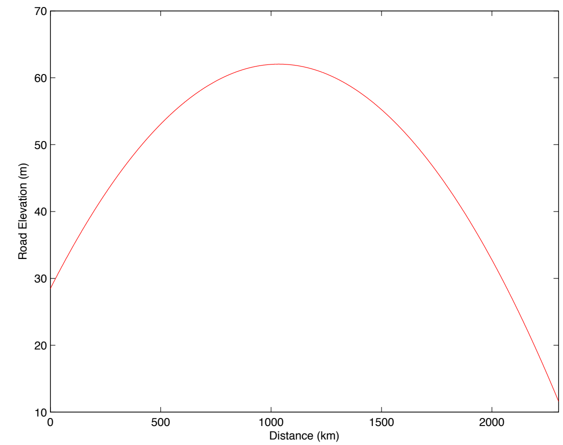
Calculation of bridge centerline curve

*Using ***UCLA*** automated image-based structural model development program

*Using ***UCLA*** automated image-based structural model development program



Determination of ground elevations

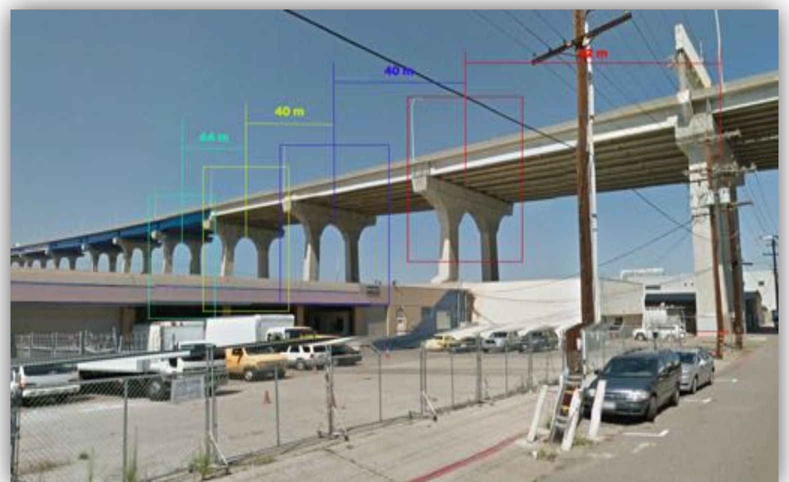


Determination of road elevations

*Using ***UCLA*** automated image-based structural model development program

A Case Study: San Diego – Coronado Bridge

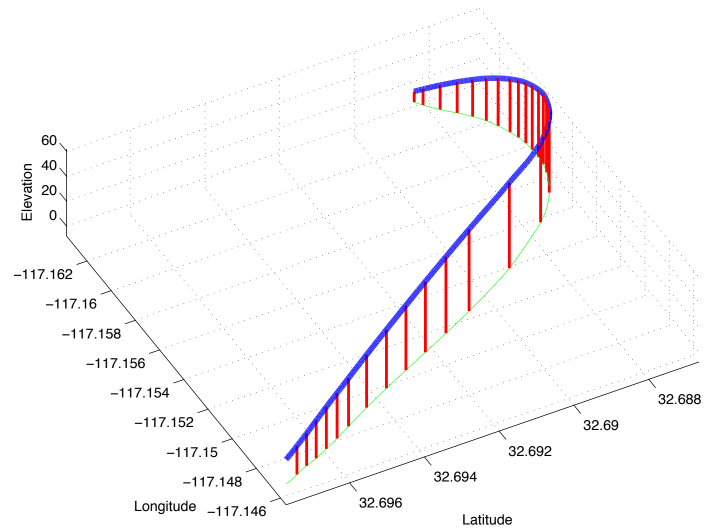
Using of image processing to identify bent locations and developing of wireframe model



Identification of bent locations

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

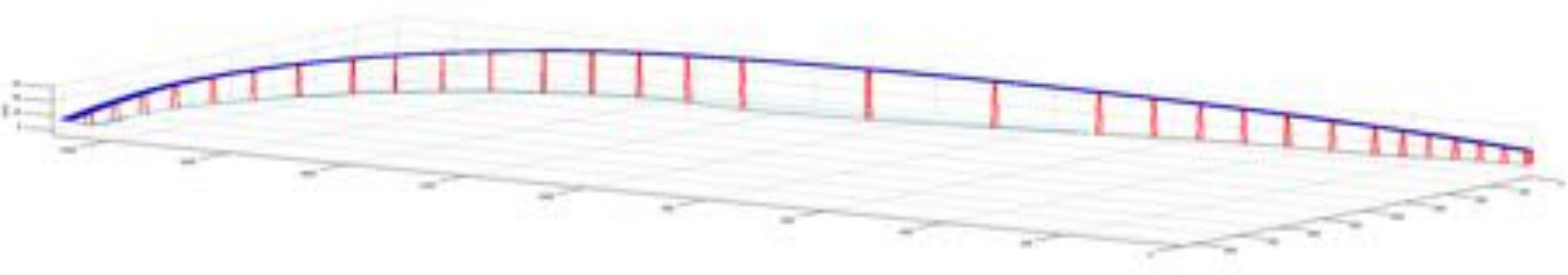
*Using **UCLA** automated image-based structural model development program via *Wireframe Model Builder Module*



Establishing of preliminary wireframe model

A Case Study: San Diego – Coronado Bridge

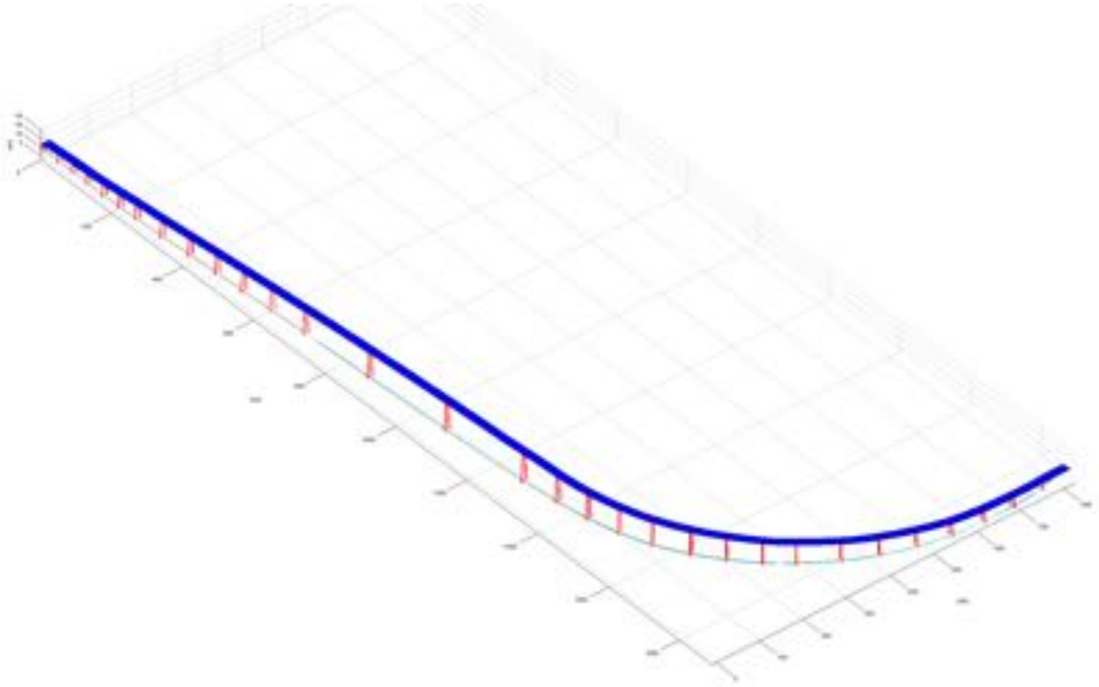
Using of image processing to identify bent locations and developing of wireframe model



Final wireframe model

A Case Study: San Diego – Coronado Bridge

Using of image processing to identify bent locations and developing of wireframe model



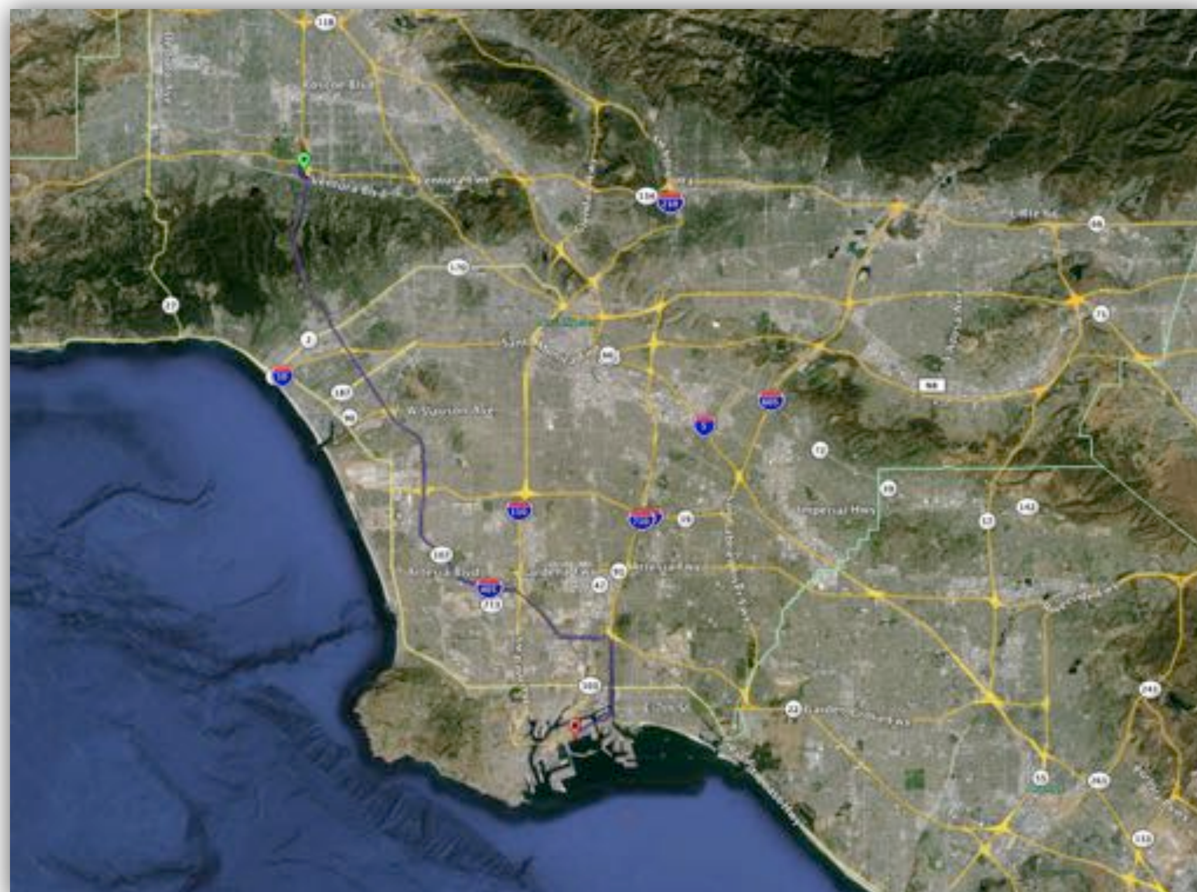
Final wireframe model

Envisioned Route of Study

US-101/I-405 Interchange to Port of Los Angeles

Regional assessment

US-101/I-405 Interchange to Port of Los Angeles



UCLA

Thank you!