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Regional Seismic Risk Assessment of a Los Angeles Bridge Network Using a New Generation of Fragility Functions

Henry V. Burton, S.E., Ph.D., Presidential Chair and Associate Professor

Department of Civil and Environmental Engineering,

University of California, Los Angeles

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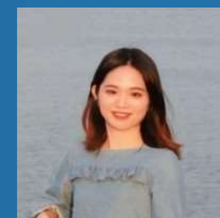
Project Team

Henry Burton
UCLA

Chenhao Wu
UCLA

Yazhou (Tim) Xie
McGill University



Shanshan Chen
McGill University

Jamie Padgett
Rice University

Mike Mieler
Arup

Ibbi Almufti
Arup

Core Team

Adam Zsarnoczay
Stanford

Selim Gunay
Berkeley

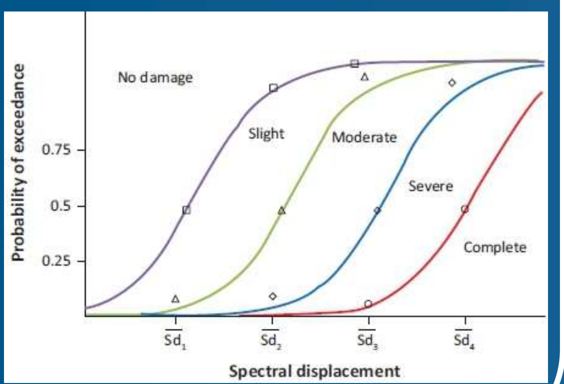
Vesna Terzic
CS Long Beach

Collaborators

Bridge Vulnerability Characterization for Regional Risk Assessment

1st Generation

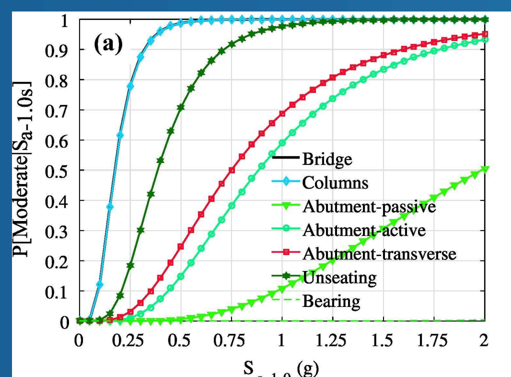
- System-Level Fragilities
- "Low" Resolution Bridge Definition
- Limited Uncertainty Consideration



https://scielo.org.za/img/revistas/jamba/v10n1/09f06.jpg

2nd Generation

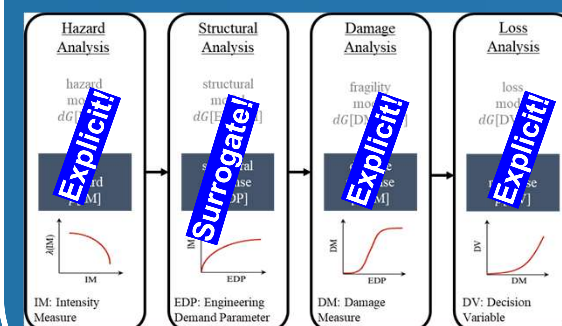
- "Pre-developed" component-level fragilities
- "Moderate" Resolution Bridge Definition
- Enhanced Uncertainty Consideration



Mangalathu et al. 2017

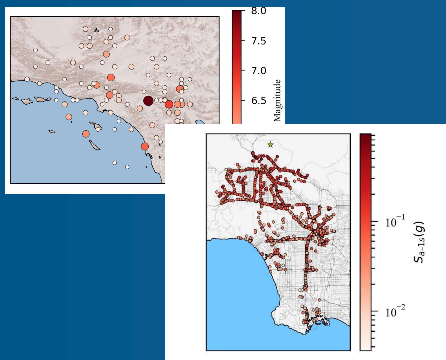
3rd Generation

- Multi-Fidelity (Explicit + Surrogate) Structural Modeling and Performance Assessment
- Multi-Resolution Bridge Definition
- Comprehensive Uncertainty Quantification

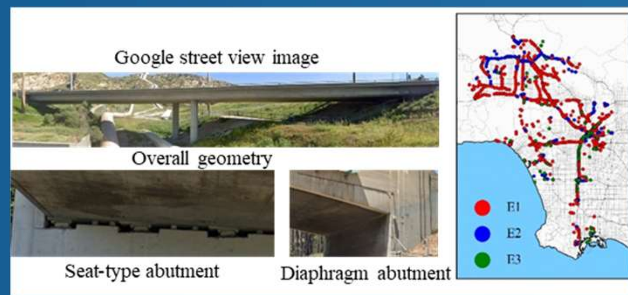


Increasing Fidelity and Resolution + Improved Uncertainty Quantification

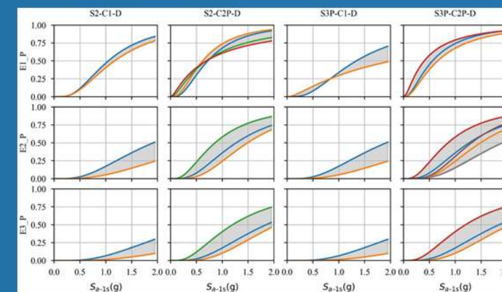
Project Overview



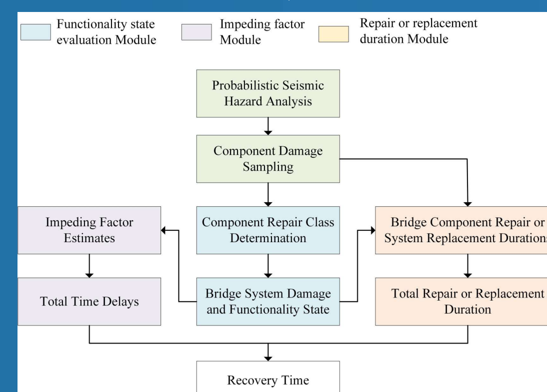
1. Regional Seismic Hazard Characterization



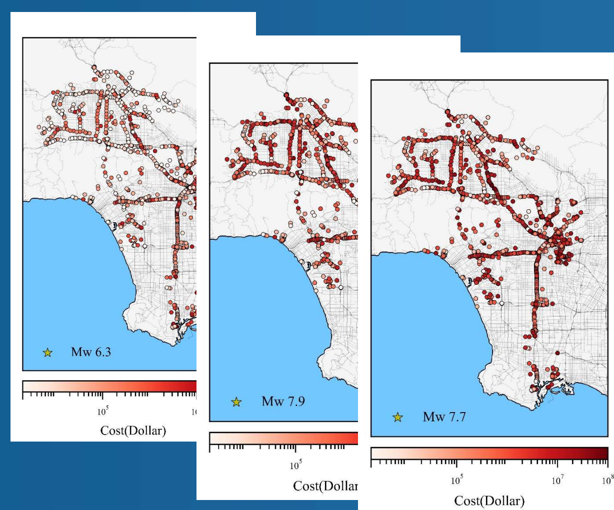
2. Inventory Capture and Group Classification



3. Component-Fragility Definition and Assignment



4. Development of Bridge-Specific Repair Cost and Functional Recovery Model

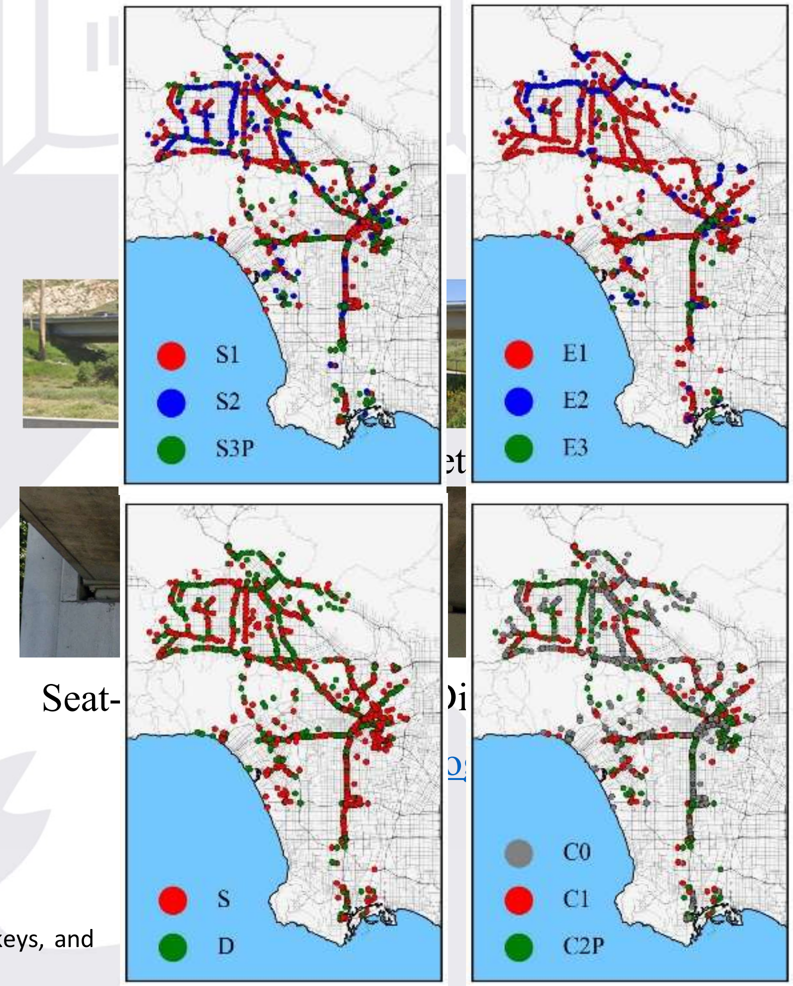


5. Regional Seismic Impact Assessment

Bridge grouping

Table 1. Nomenclature used for grouping LA bridges.

Parameters	Design attributes	Nomenclature
Design era	Era 1 (pre 1970)	E1
	Era 2 (1971-1990)	E2
	Era 3 (post 1991)	E3
Span number	Single span	S1
	Two spans	S2
	More than two spans	S3P
Bent type	No column bent (i.e., Single span)	C0
	Single column bent	C1
	Multiple columns bent	C2P
Abutment type	Diaphragm	D
	Seat type	S



- Design era represents a change in seismic design philosophy among bridges
- The number of spans and columns in bent has shown evident influences on bridge performance
- Bridges with seat-type abutments have extra components or damage scenarios, such as bearings, shear keys, and span unseating.

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Synthesis of the next-generation fragility models

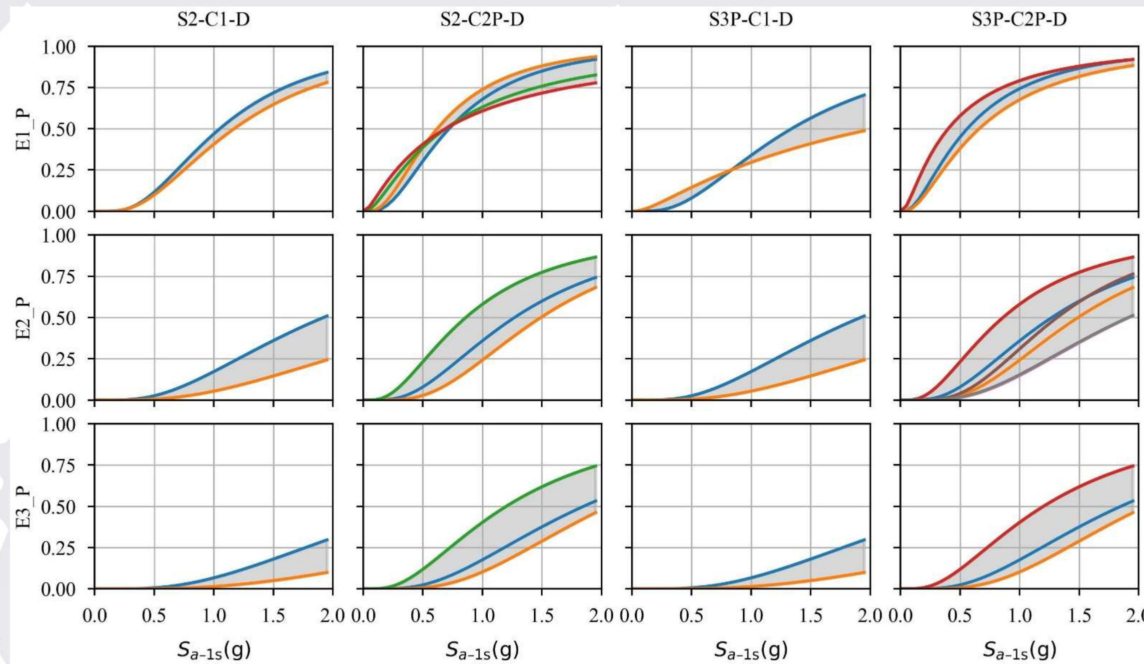
HAZUS Model:

- Small number of classes (e.g., pre- and post-1975 as two design eras)
- Neglecting the effect of abutment type
- Developed using a 2D simplified method
- Failing to address uncertainties in geometric and material attributes
- System-level fragility models

New-Generation Fragility Models:

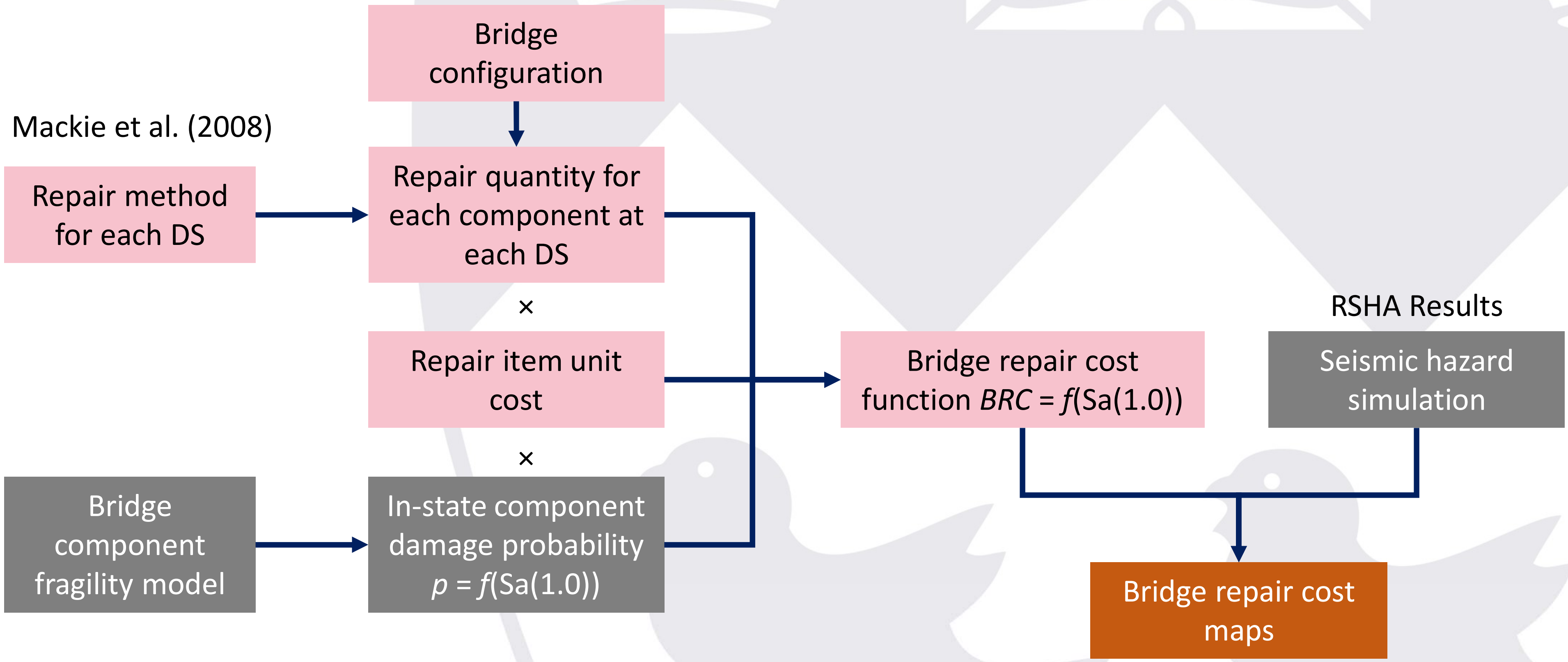
- Larger number of classes (~25)
- Effect of abutment type considered
- Developed using advanced finite element models
- Capturing uncertainties in geometric and material attributes of California bridges
- Component-level fragility models

Column fragility, diaphragm bridge, complete damage state



(Mangalathu 2017; Mangalathu et al. 2017; Soleimani 2017; Zheng 2021; Mangalathu et al. 2018; Jeon et al. 2019; Soleimani et al. 2017)

Bridge repair cost modeling



Mackie KR, Wong JM, Stojadinovic' B. Integrated probabilistic performance-based evaluation of benchmark reinforced concrete bridges. Pacific Earthquake Engineering Research Center; 2008.

Issues in Mackie's model and modifications

1. Some repair quantity items are bridge geometry dependent (e.g., Repair minor column spalls = 25% × (column surface area) × (cover + 1'')). Mackie et al. (2008) only considers a testbed bridge (Type 1A), which has one fixed configuration (a two-span seat-type bridge) and a specific geometry.

Solution: Identify component geometric parameters (column, abutment wall, wing wall, shear key, pile foundation, deck depth, etc.) for each bridge.

- NBI database
- PhD thesis from Zheng (2021)
- Caltrans Engineering Manuals (https://dot.ca.gov/programs/engineering-services/manuals)

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Issues in Mackie's model and modifications

2. Mackie et al. (2008) has a different damage state (DS) definition (not matching HAZUS's definition and those used for the new generation fragility models); it does not consider repair actions for span unseating

Solution: Remapping DS definition from Mackie's model to the HAZUS definition. Develop repair cost models (repair method, quantify, unit cost) for missing DS and for span unseating at four DSs.

	Probability (%) of selecting different repair strategies			
Repair strategy	S	M	E	C
Jack bridge into place[d]	15%	42%	41%	0%
Do nothing	77%	12%	0%	0%
Replace bridge bearings[a]	8%	46%	0%	0%
Replace bridge deck[c] and bearings[a]	0%	0%	59%	100%

Span Unseating

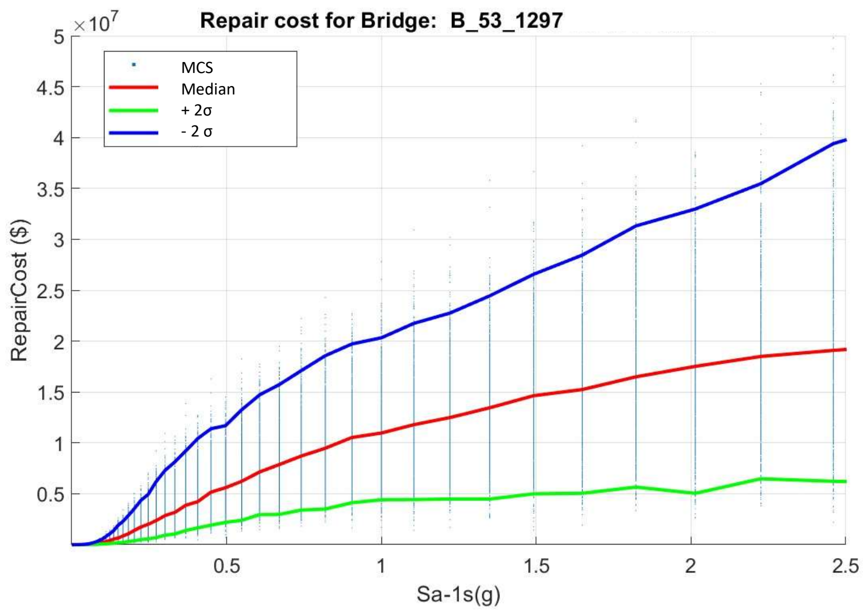
Padgett, J. E., and R. DesRoches. 2007. "Bridge functionality relationships for improved seismic risk assessment of transportation networks." Earthquake Spectra 23 (1): 115–130. https://doi.org/10.1193/1.2431209.

Issues in Mackie's model and modifications

3. Repair item unit cost in Mackie et al. (2008) is based on 2007 data

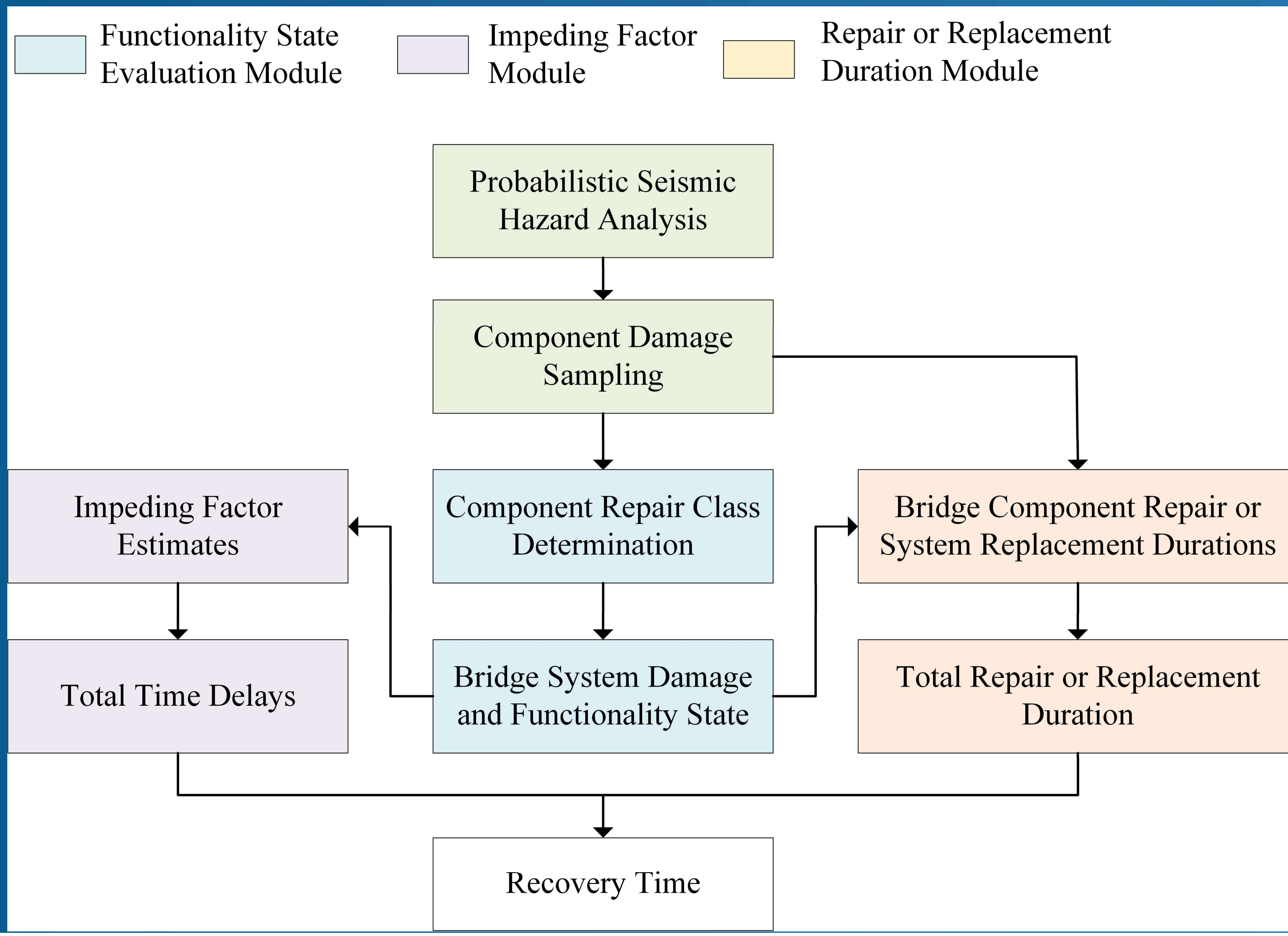
Solution: Replace it with the Caltrans Contract Cost Data (2023) (https://sv08data.dot.ca.gov/contractcost/)

Bridge repair cost function



- Cost function development: For each bridge, Monte Carlo simulation (MCS) to capture uncertainties in in-state damage probabilities (i.e., from fragility curves) and unit costs for each repair item.
- Cost function utilization: at each Sa-1 level, fit the bridge repair cost as a normal distribution function and generate the bridge cost through normal distribution sampling.

Bridge-Specific Post-Earthquake Functional Recovery Model



Framework Supported by Information and Data from Expert Elicitation

- Expert elicitation sought from:
  - Caltrans Field Engineers
  - Senior Consulting Bridge Engineer (> 30 years experience)
  - Southern California Bridge Contractor

- Information and data include:
  - Type sequencing and duration of impeding factors
  - Bridge closure and reopening decision making
  - Sequencing and duration for component-level repairs
  - Replacement durations

November 23: Round 1 Interviews with Caltrans Field Engineers

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January 24: Round 2 Interviews with Caltrans Field Engineers

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February 24: Interviewed Senior Consulting Bridge Engineer

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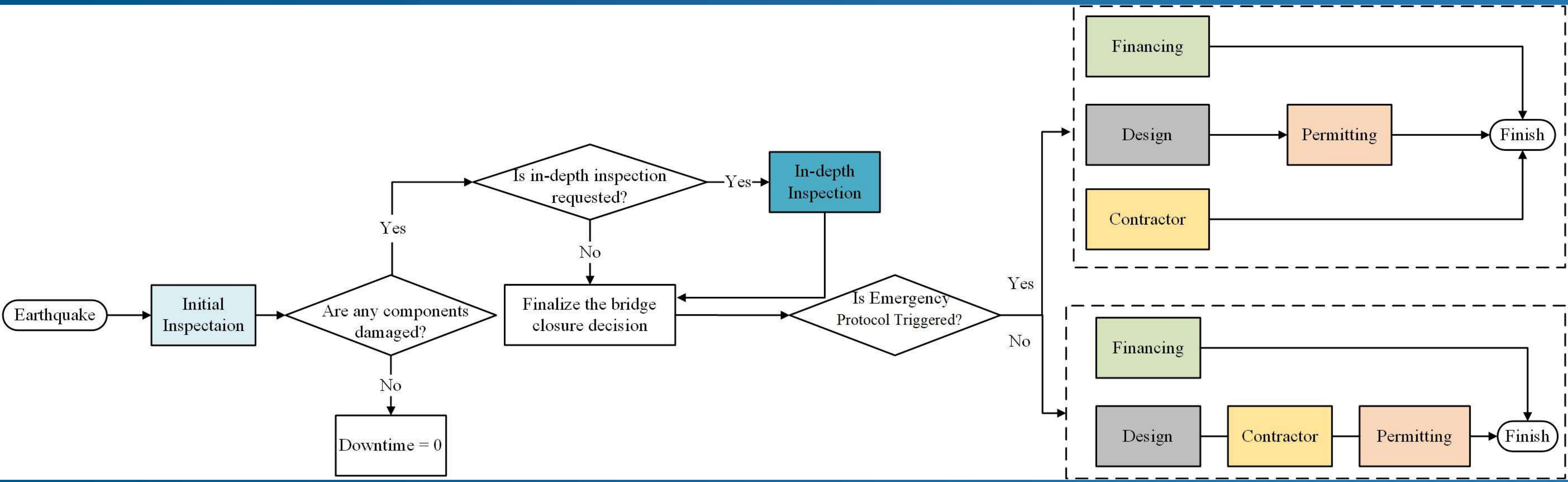
March 24: Interviewed Southern California Bridge Contractor

Impeding Factors and Sequencing**



** Based on discussions with Caltrans i.e., will need to be modified for Non-Caltrans bridges

Time Delays Associated with Impeding Factors

Impeding Factor	System Damage State							
	Slight		Moderate		Extensive		Complete	
	Min	Max	Min	Max	Min	Max	Min	Max
Initial Inspection	0 to 6 hours							
In-depth Inspection	3 days	7 days	3 days	7 days	2 hours	36 hours	0	
Financing	6 months	2 years	0	6 months	0			
Design	0		1 month	2 months	1 week	2 months	2 weeks	2 months
Permitting	1.5 to 3 months				1 to 7 days			
Contractor Acquisition	1 year	2 years	3 months	6 months	6 to 48 hours			

** Based on discussions with Caltrans, a bridge engineer and a bridge builder

Functionality State Definitions

Functionality state	Applicable Phase(s)
FS1: Fully Functional FS2: Minor-to-Moderate Lane Closure FS3: Moderate-to-Extensive Lane Closure	Initial response and reopening phases
FS4: Reopen with Weight Restriction FS5: Reopen with Minor Lane Closure FS6: Reopen with Weight Restrictions and Minor Lane Closure	Reopening phase
FS7: Complete Closure	Initial response and reopening phases

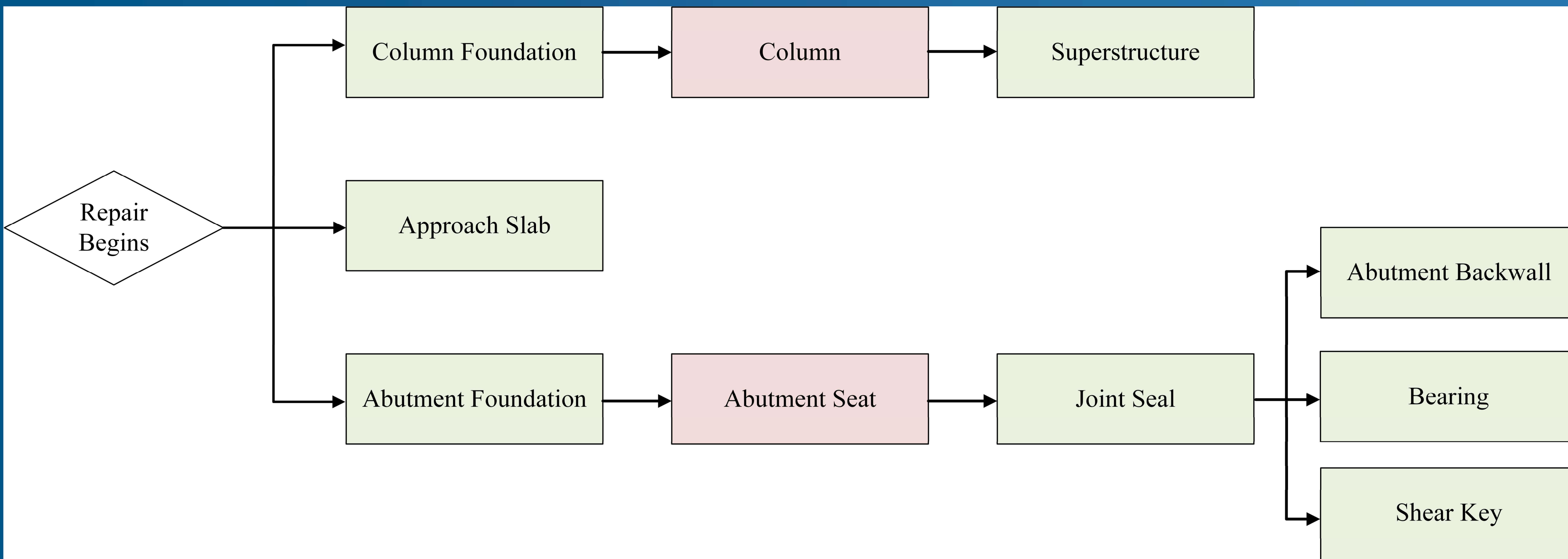
* The “fully repaired” state is one where all components are intact or have been repaired and the bridge is fully functional. Since it does not represent a change in functionality relative to FS1, it is not listed in the table.

Component Repair Class Definitions

Component Type	Damage State				
	No Damage	Slight	Moderate	Extensive	Complete
Column	RC1	RC2 for $N_c \geq 1 \& F_c < 50\%$ RC3 for $F_c \geq 50\%$	RC3 for $N_c \geq 1 \& F_c < 50\%$ RC4 for $F_c \geq 50\%$	RC4 for $N_c \geq 1 \& F_c < 50\%$ RC5 for $F_c \geq 50\%$	RC5
Abutment seat	RC1	RC2 for $N_c = 1$ RC3 for $N_c = 2$	RC3 for $N_c = 1$ RC4 for $N_c = 2$	RC4 for $N_c = 1$ RC5 for $N_c = 2$	RC5
Superstructure	RC1	RC2	RC2 for $N_c \geq 1 \& F_c < 50\%$ RC3 for $F_c \geq 50\%$		
Column foundation	RC1	RC2	RC2 for $N_c \geq 1 \& F_c < 50\%$ RC3 for $F_c \geq 50\%$		
Abutment foundation	RC1	RC2	RC2 for $N_c = 1$ RC3 for $N_c = 2$		
Bearing	RC1	RC2	RC2 for $N_c = 1$ RC3 for $N_c = 2$		
Shear key	RC1	RC2	RC2 for $N_c = 1$ RC3 for $N_c = 2$		
Abutment backwall	RC1	RC2	RC2 for $N_c = 1$ RC3 for $N_c = 2$		
Approach slab	RC1	RC2	RC2 for $N_c = 1$ RC3 for $N_c = 2$		
Joint seal	RC1	RC2	RC2 for $N_c = 1$ RC3 for $N_c = 2$		

*N_c denotes the number of damaged components, and F_c denotes the fraction of damaged components.

Component Repair Sequencing (Seat-Type Bridge)**



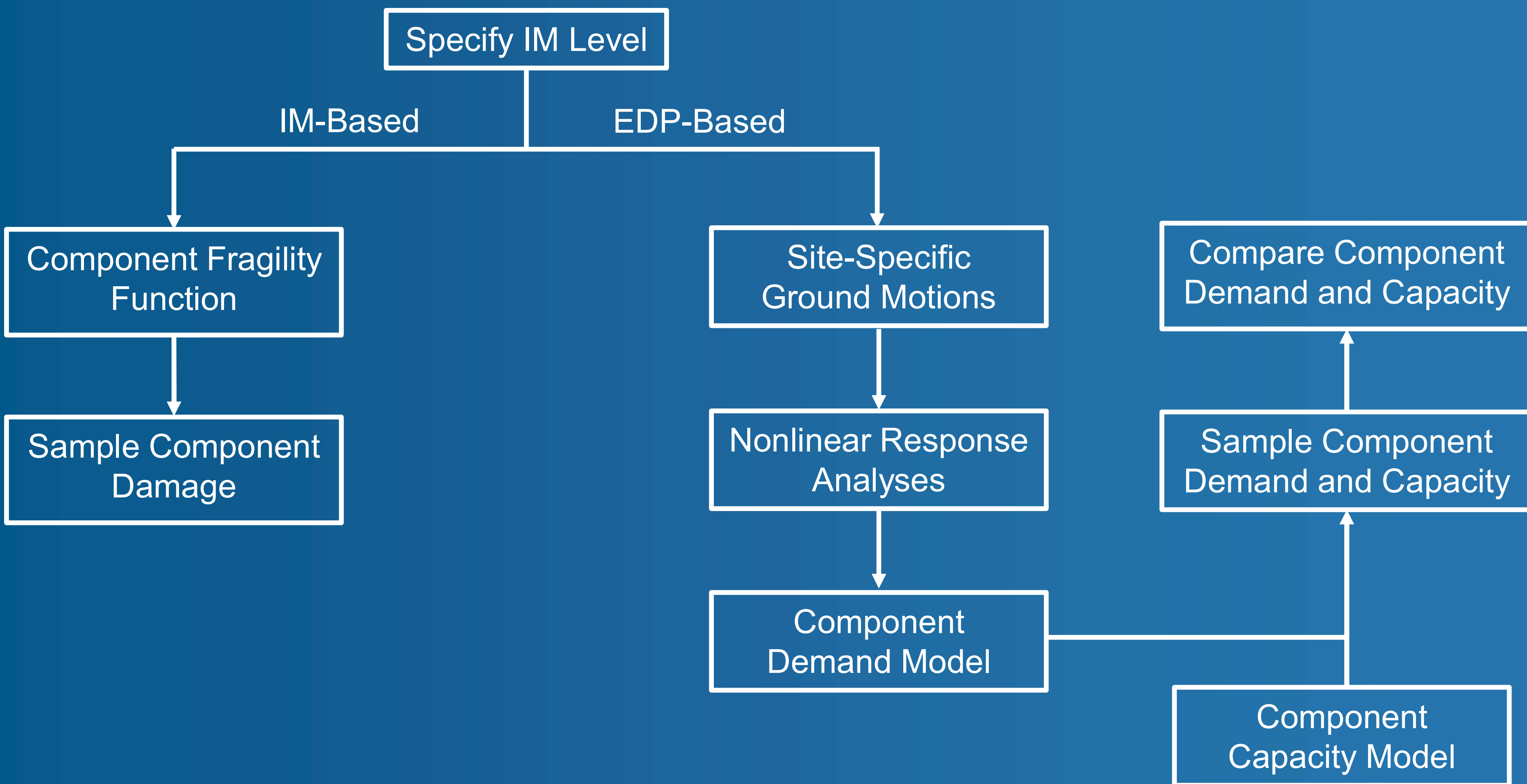
** Based on discussions with Caltrans, a bridge engineer and a bridge builder

Component Repair Durations (Per Unit)**

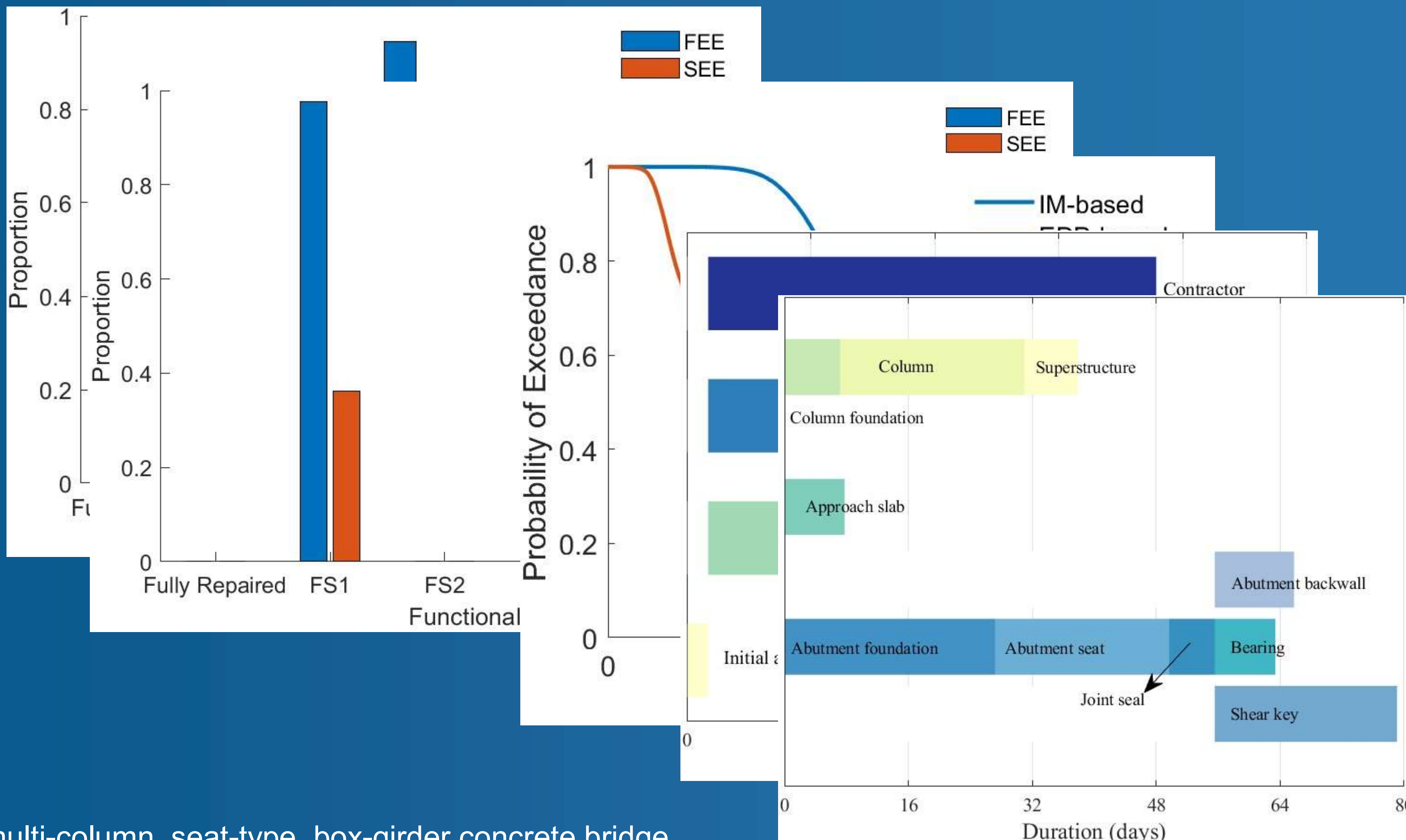
Component Type	Median repair duration (days)						Required No. of Workers					
	Slight		Moderate		Extensive		Slight		Moderate		Extensive	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Column	3	5	3	10	33.5	46	1	6	2	6	3	6
Abutment seat	3	5	4.5	15	42	65	1	6	3	6	3	6
Superstructure	3	5	3	10			4	6	4	6		
Column foundation	6	17	6	17			3	6	3	6		
Abutment foundation	6	17	6	17			3	6	3	6		
Bearing	1.5	6	1.5	6			2	6	2	6		
Shear key	3	5	12	25			1	6	3	6		
Abutment backwall	4	9	12.5	26			2	6	2	6		
Approach slab	1	4	2	15			4	7	4	7		
Joint seal	2	4	2	4			4	6	4	6		

** Based on discussions with Caltrans, a bridge engineer and a bridge builder

IM-Based versus EDP-Based Component Damage Assessment



Sample Results for Hypothetical Bridge**



** For two-span, multi-column, seat-type, box-girder concrete bridge

Summary and Next Steps

- At a high level, this project seeks to advance bridge vulnerability characterization and assessment for regional seismic risk and resilience assessments.
- “Year 1” focused on
  - Bridge inventory (for Los Angeles) capture and group classification
  - Component-fragility definitions and assignment
  - Developing and improving methods for bridge-specific performance quantification based on post-earthquake repair cost and functional recovery.
- “Year 2” will focus on
  - Regional hazard characterization.
  - Network level performance assessment
  - Miscellaneous topics (e.g., uncertainty quantification, surrogate modeling, improving workflow efficiency, model integration into SimCenter tools)

Acknowledgements

- UCLA student funded by the PEER-TSRP Topic 2: Forward Uncertainty Quantification.

- McGill student funded by the Natural Sciences and Engineering Research Council (NSERC) of Canada.

The End