Seismic Design of a Light Rail Transit Bridge with Fault Rupture Crossing

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Presentation Outline

1. Project Overview
2. Site-Wide Fault Mapping
3. Field Exploration at Three Bridge Sites
4. Design Fault Rupture Displacements
5. Faulting Through Foundations
6. Bridge Design for Fault Rupture

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Project Overview

- 11 miles of new light rail in S. California
- 9 stations
- 7 bridges
- >4 miles of elevated viaduct
- Several miles of retaining walls
- $2.1B total cost
- 4 kilometers of the alignment affected by surface fault rupture hazard

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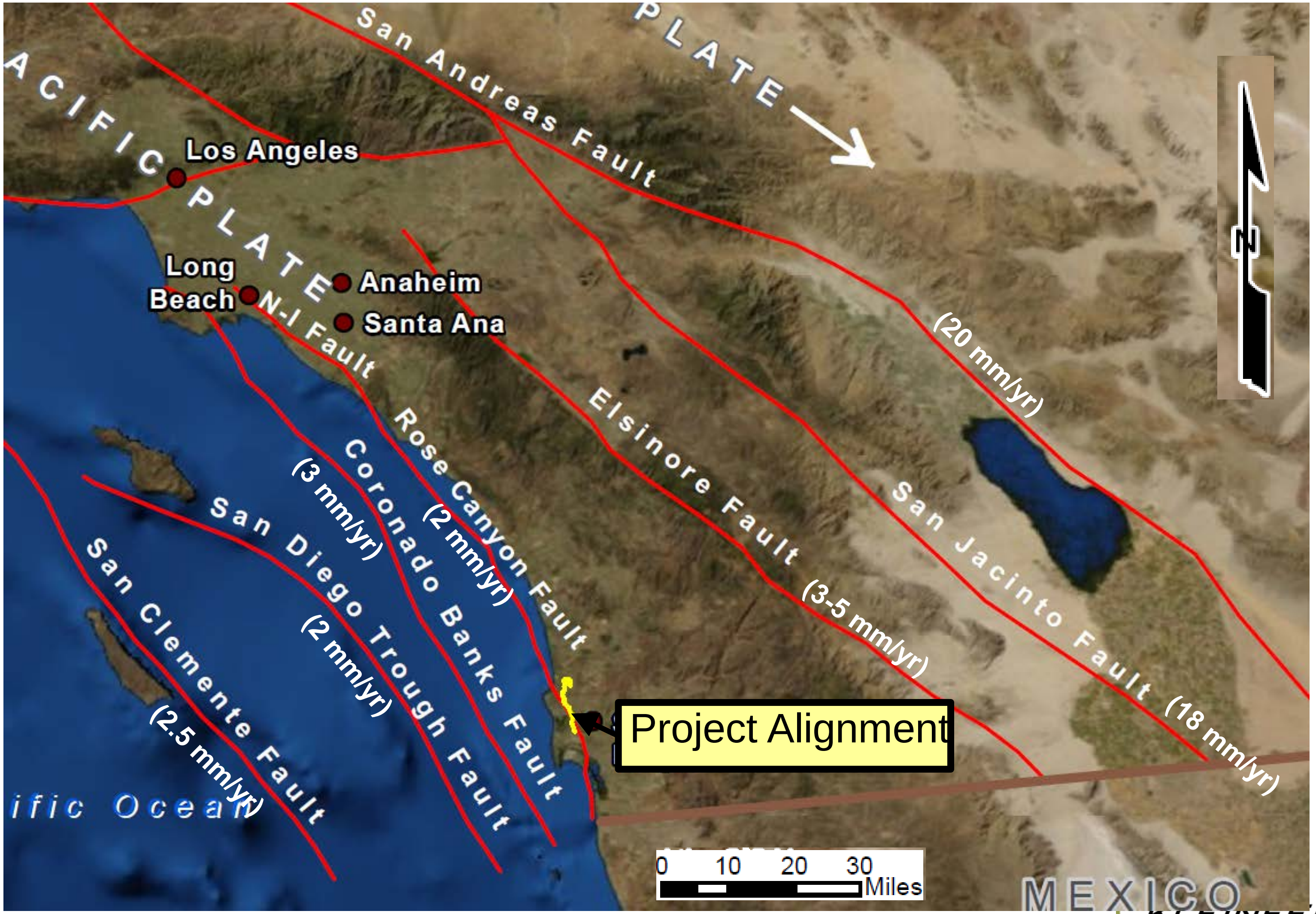
Regional Faulting



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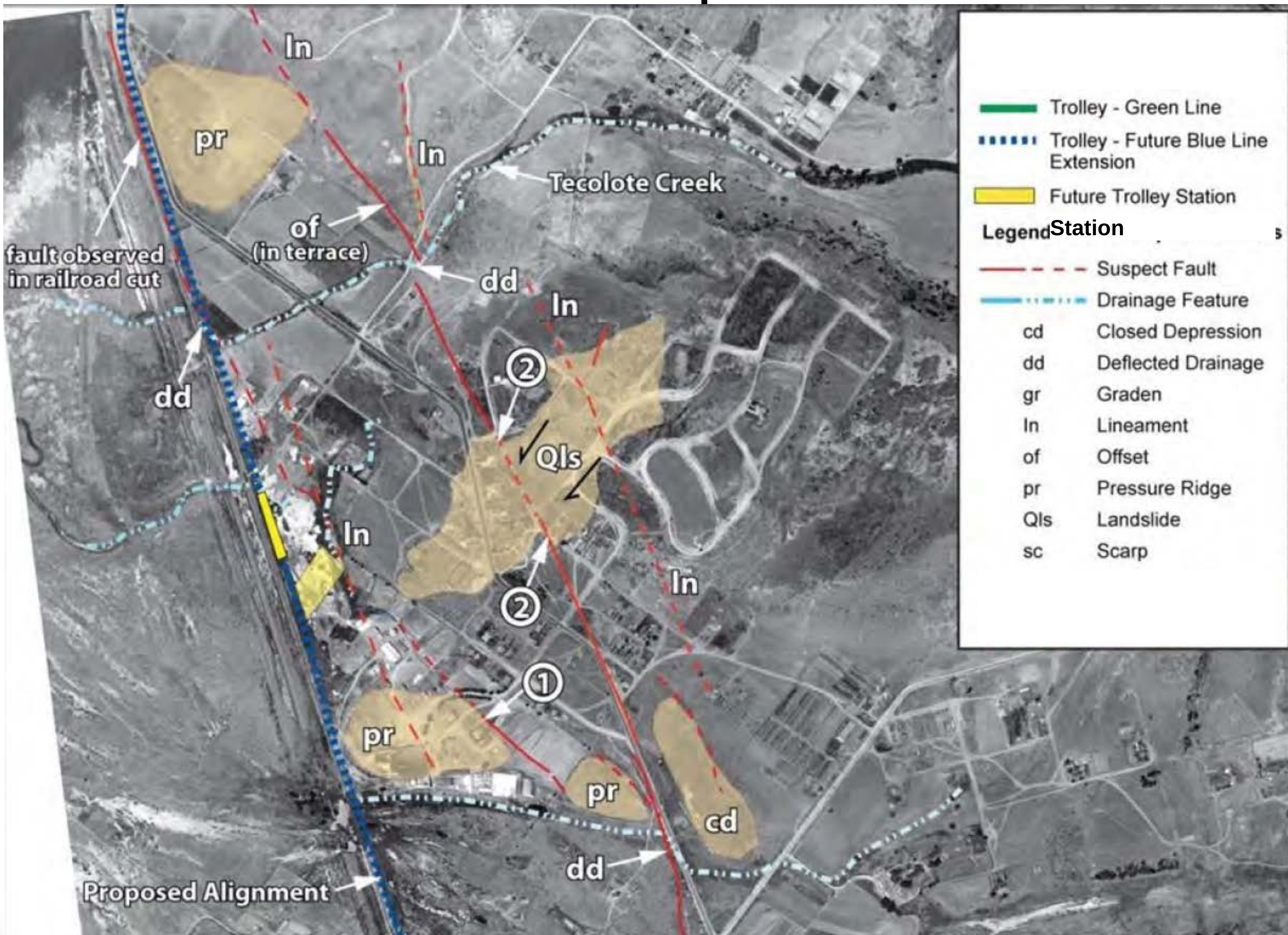
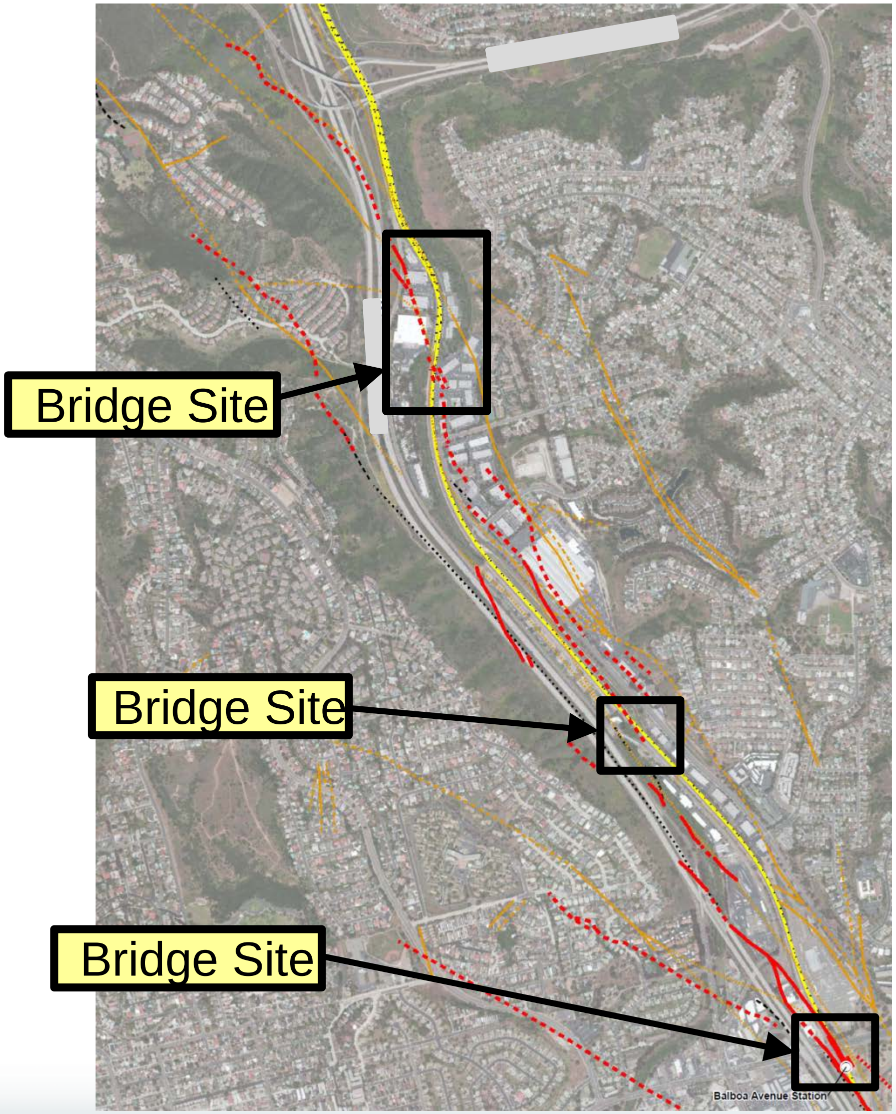
Desk Top Study – Vintage Stereoscopic Aerial Photo Interpretation



Interpretations by Scott Rugg and Tom Rockwell (Kleinfelder 2013)

Detailed Field Exploration Programs at Three Bridge Sites



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Project Alignment

Interpreted Fault Locations:

Kleinfelder (2013)

Alquist-Priolo (CDMG 1991)

City of San Diego (2008)

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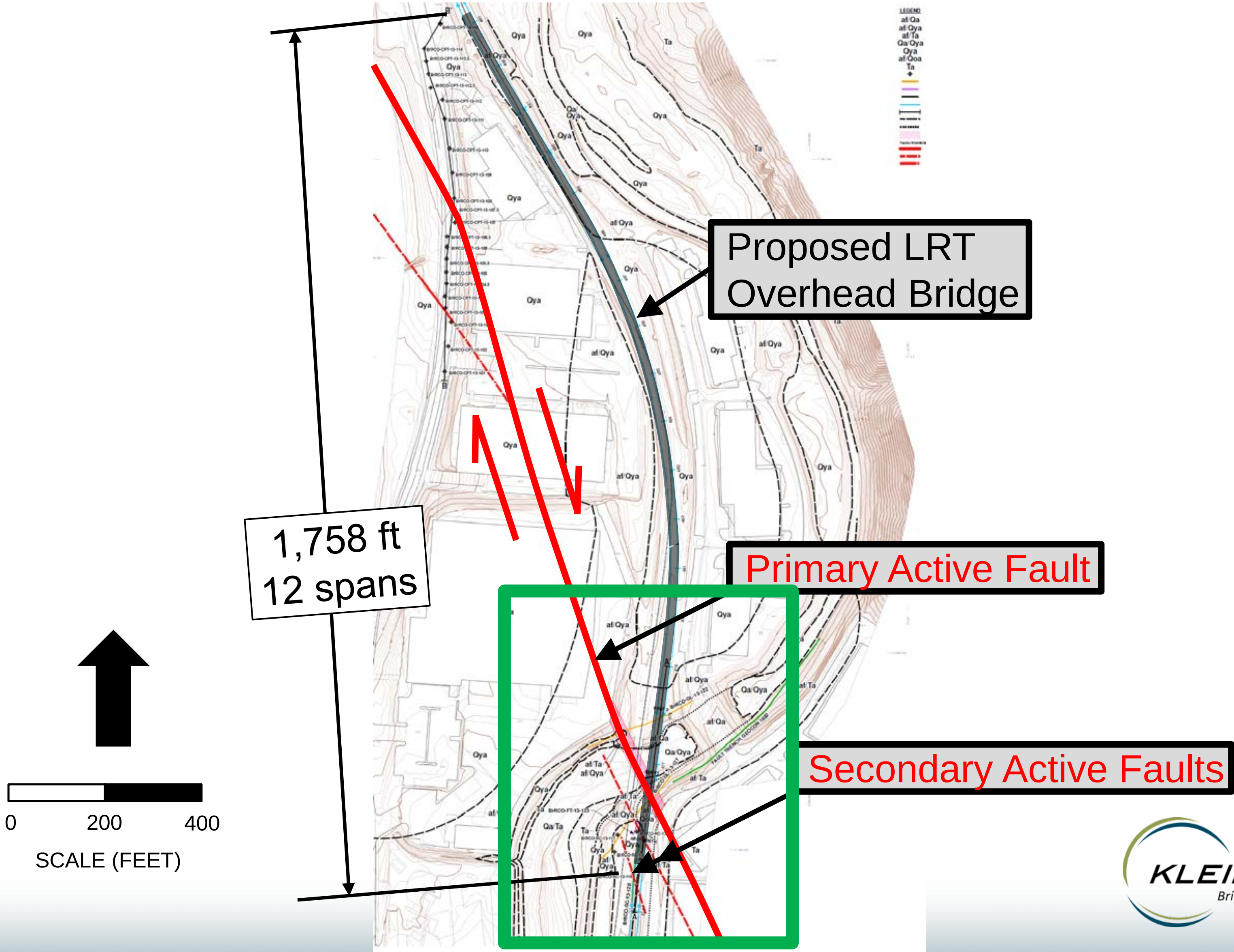
Field Exploration and Fault Mapping at LRT Overhead Bridge Site – Plan View



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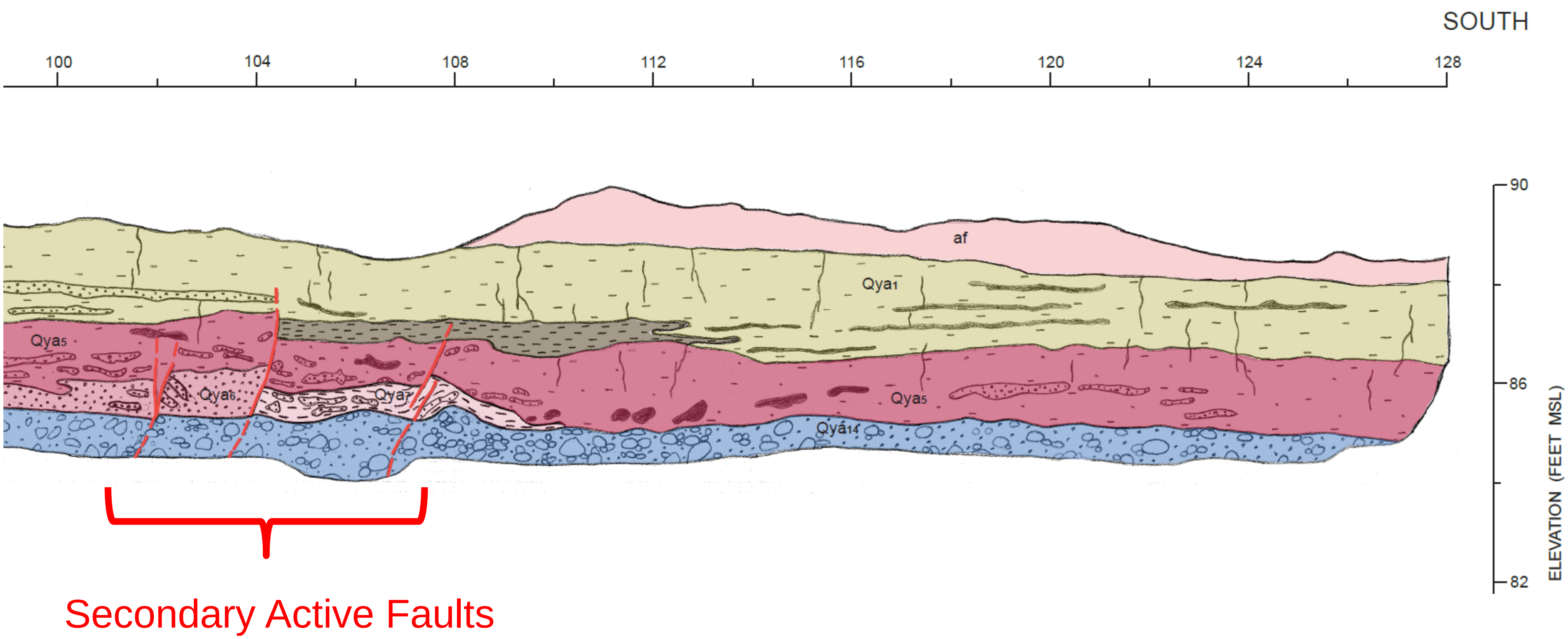
Geologic Mapping of Cut Surface



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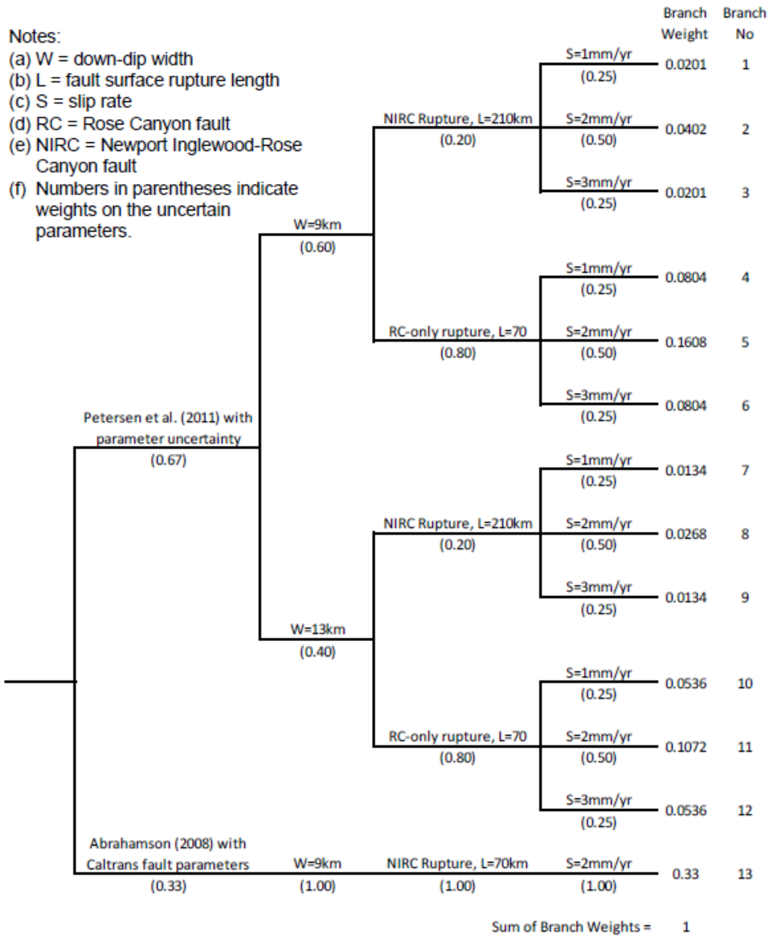
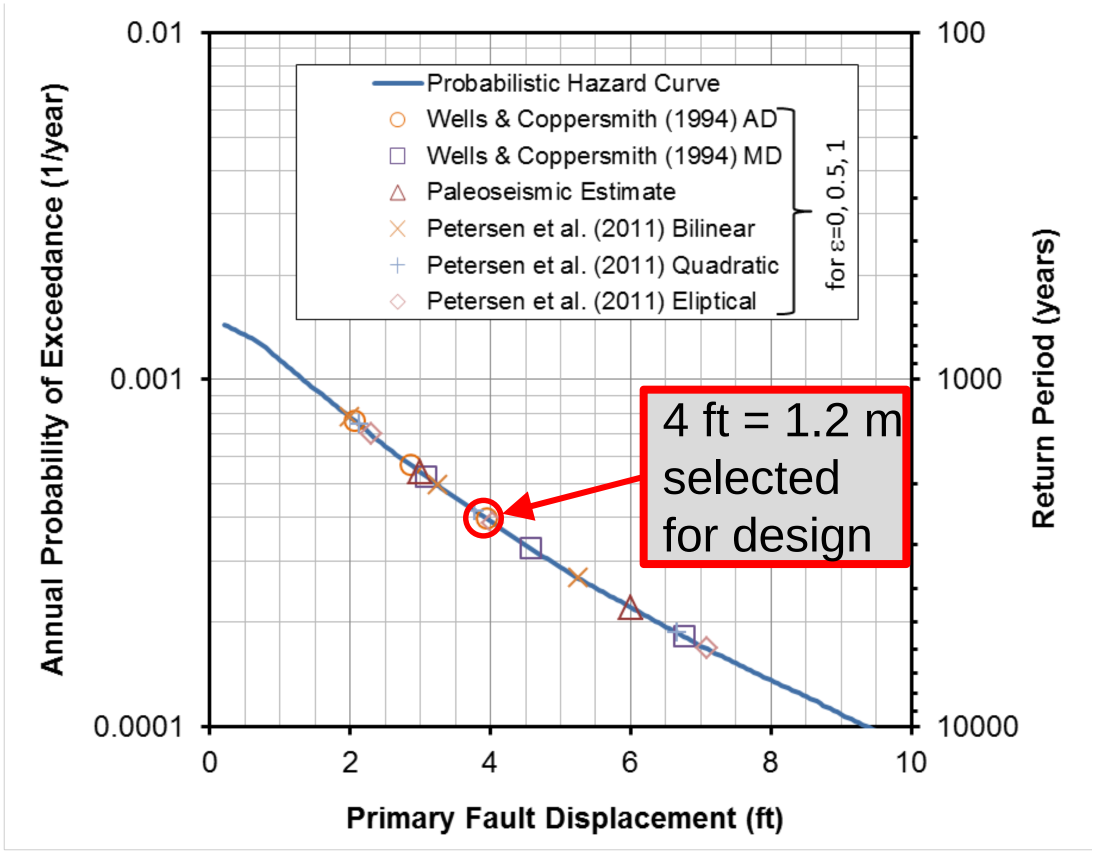
Design Fault Displacements – Deterministic and Probabilistic Analyses

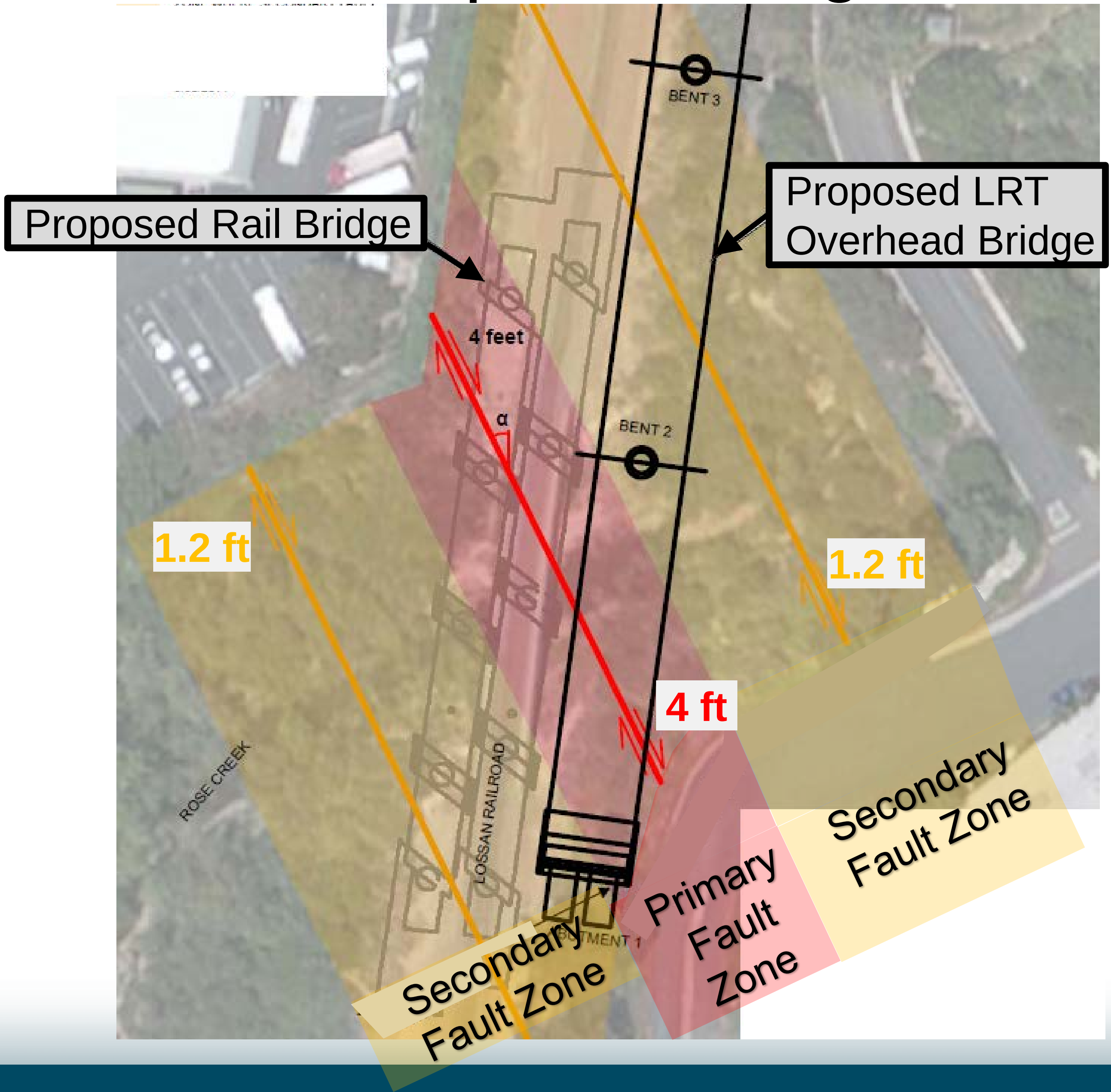


Logic tree used in PFDHA



Hazard curve with deterministic values overlain

Fault Rupture Design Scenario



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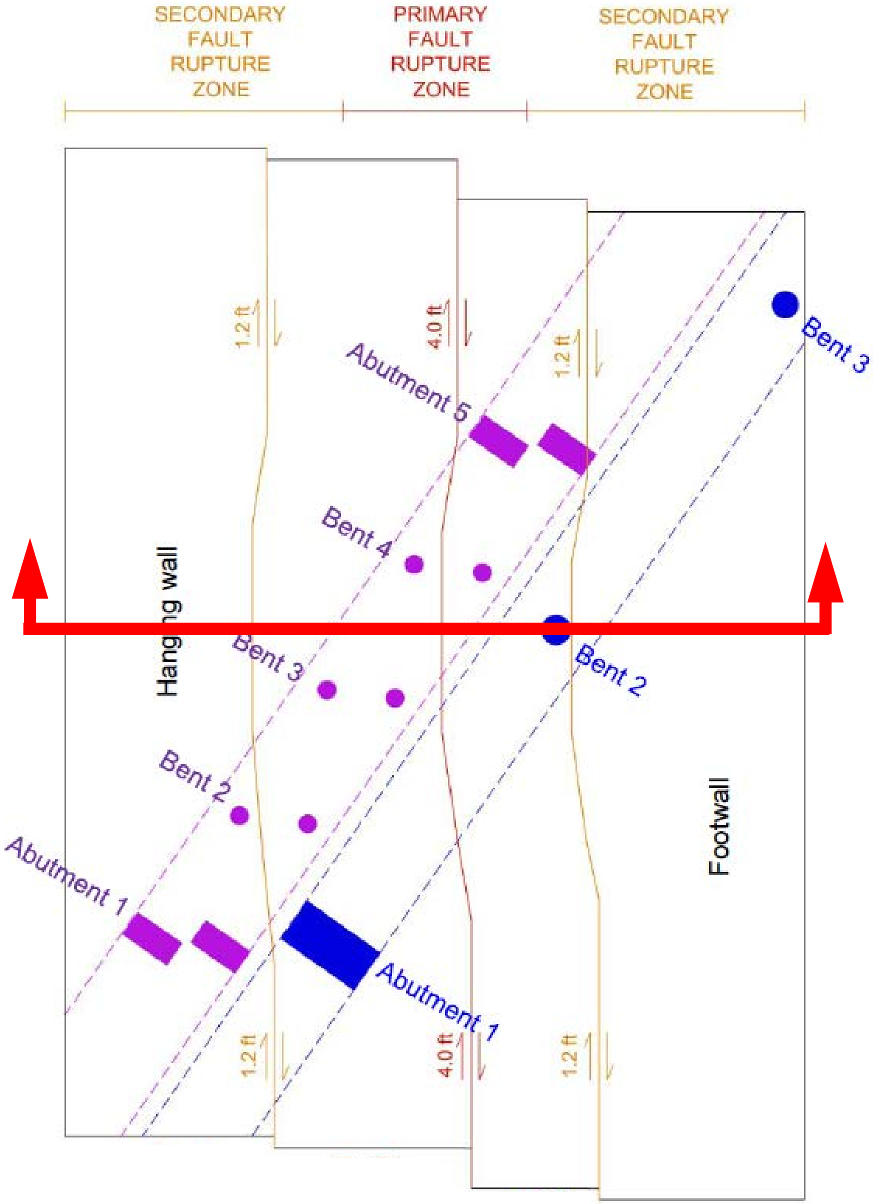
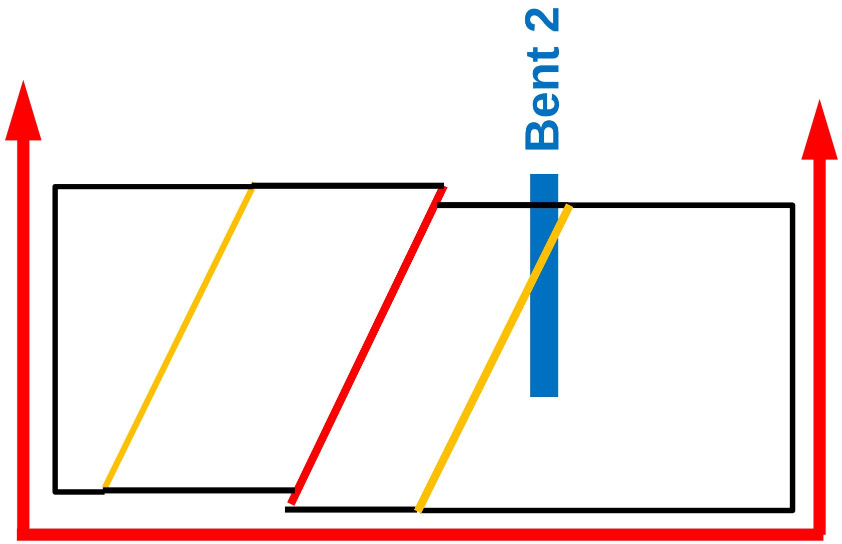
Fault Rupture Design Scenario





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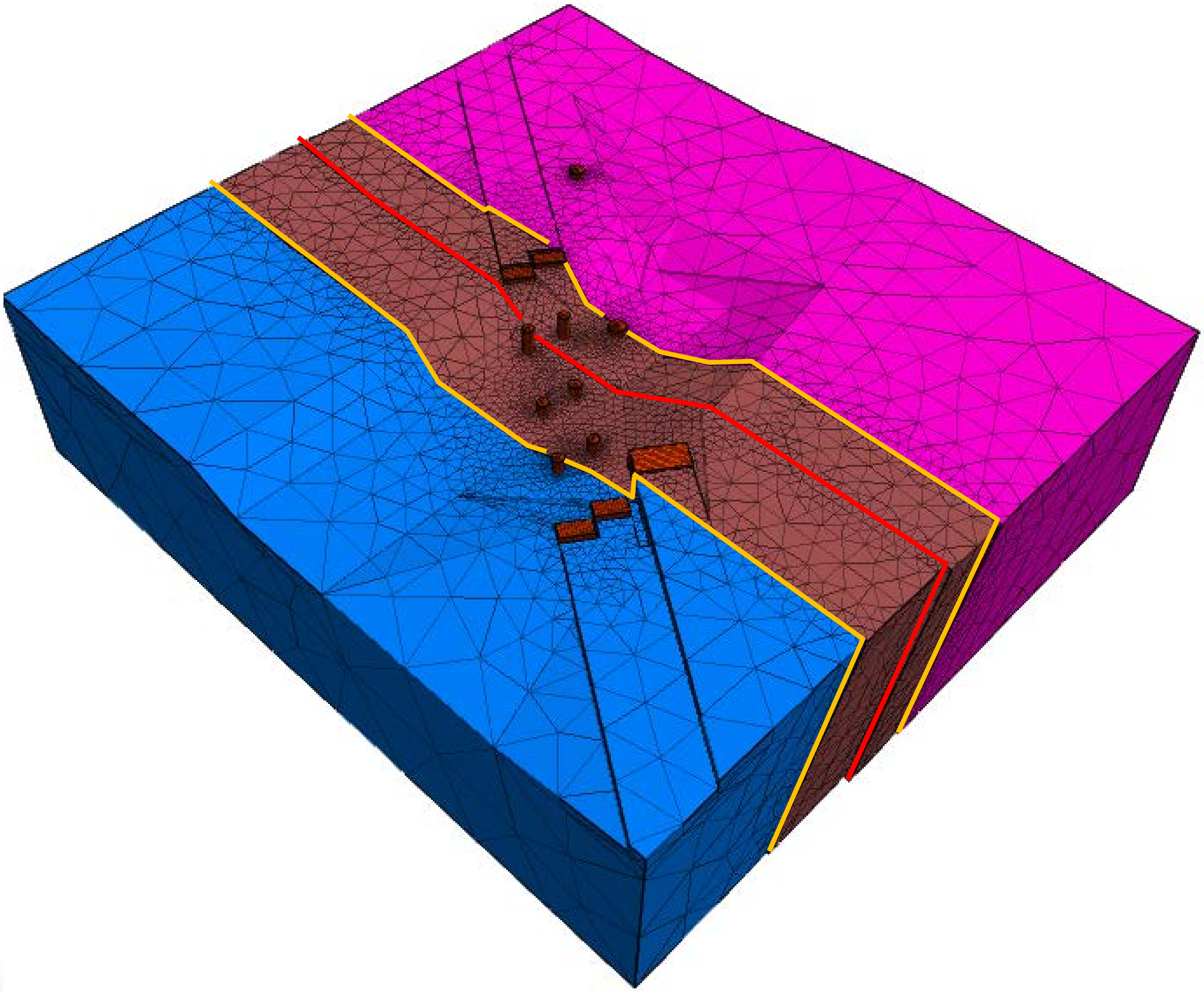
Foundation Design Strategy

- Unusual situation of faulting through foundations
- Avoid primary fault where possible
- Large Diameter CIDH Piles or mat-footings
- Modeling to evaluate foundation behavior and displacements

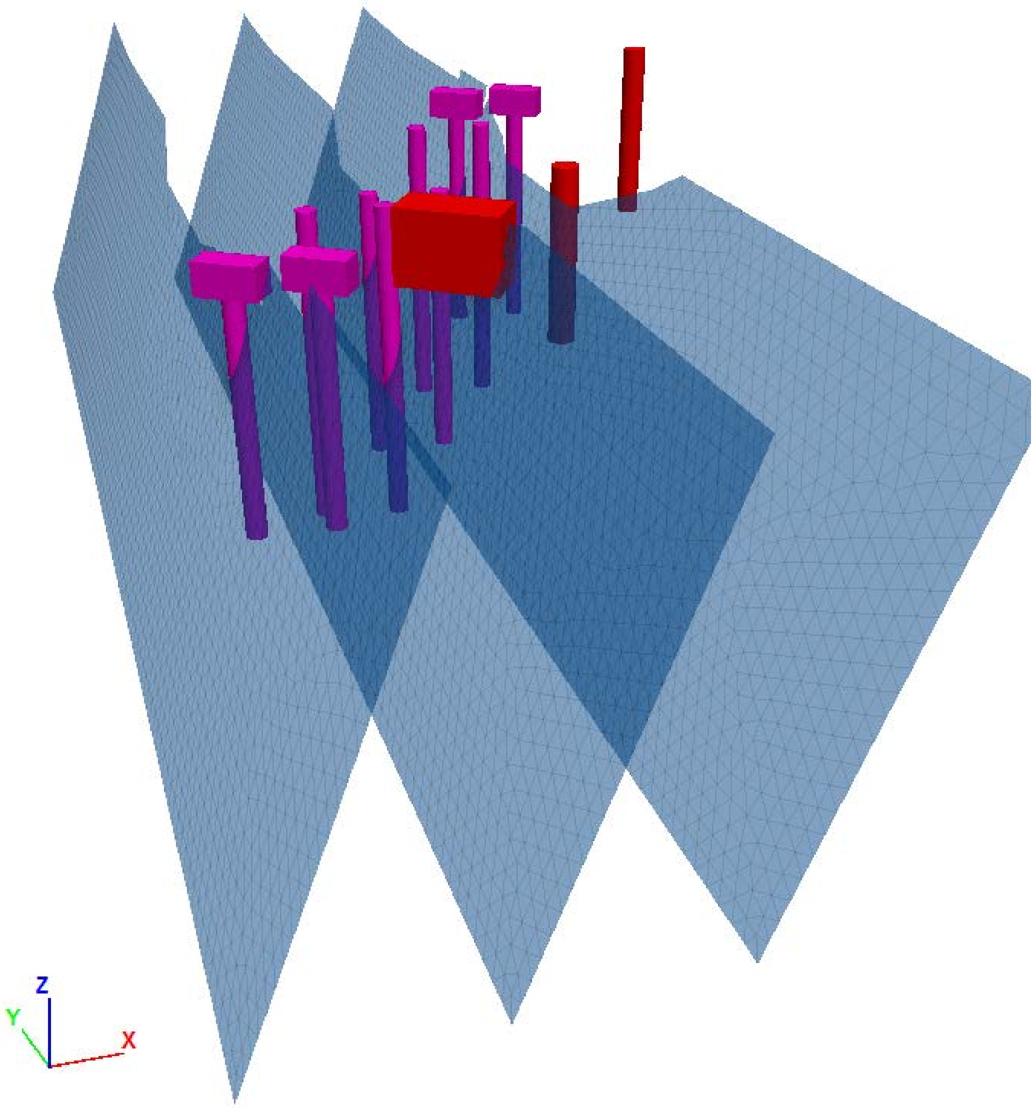
Desirable foundation behavior

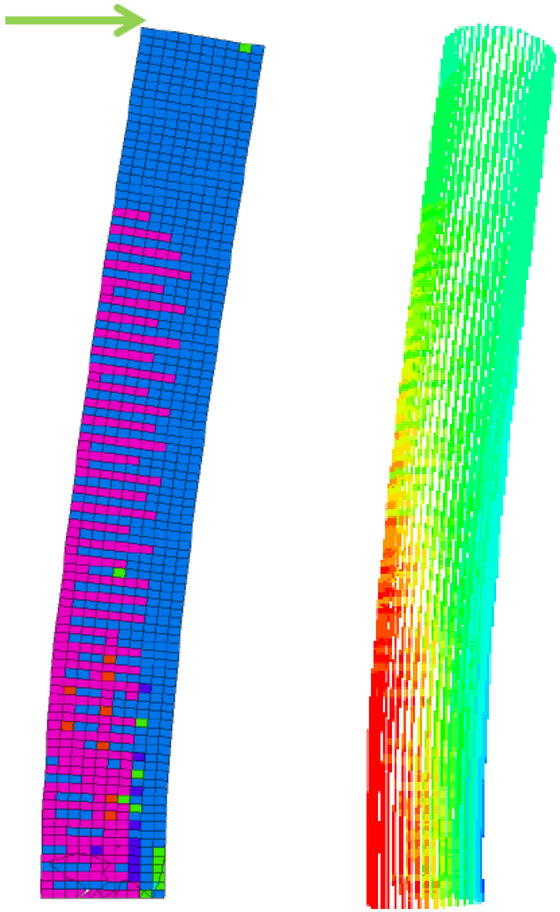
Undesirable behavior

Modeling of Soil-Fault Foundation System



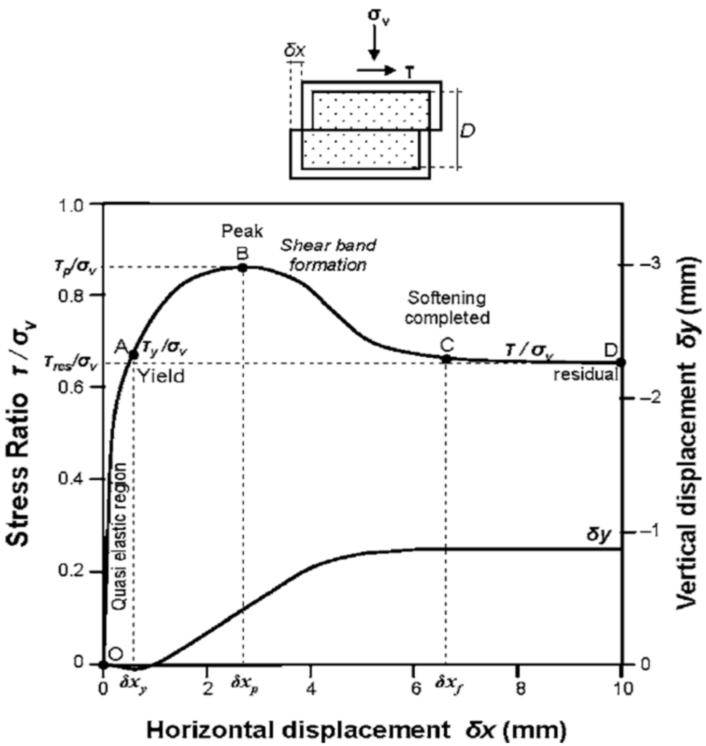
Modeling of Soil-Fault Foundation System



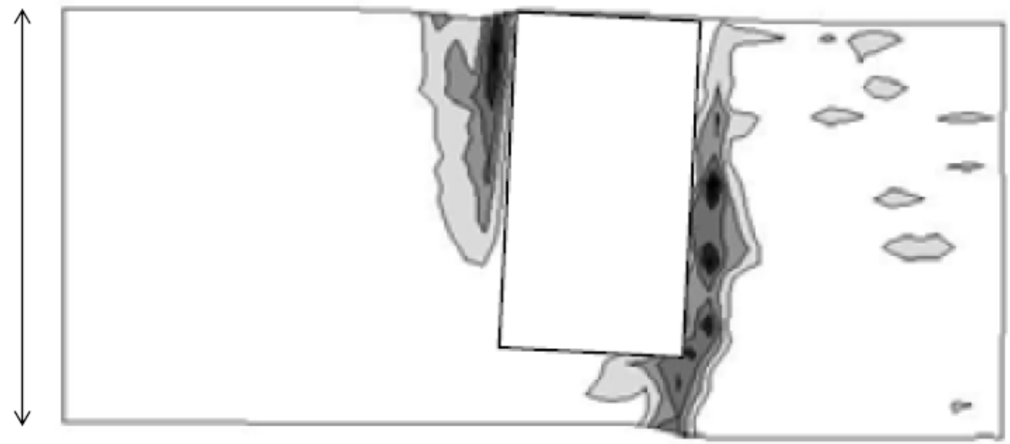


Pile Model

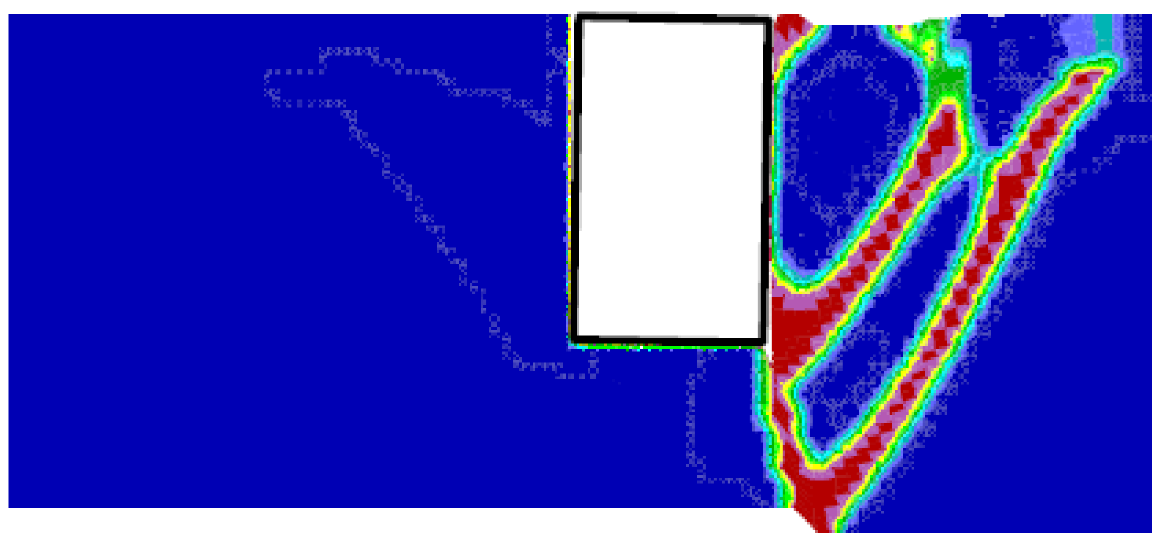
Soil Model Calibration and Validation



Constitutive model approach of Anastasopoulos et al. (2007)

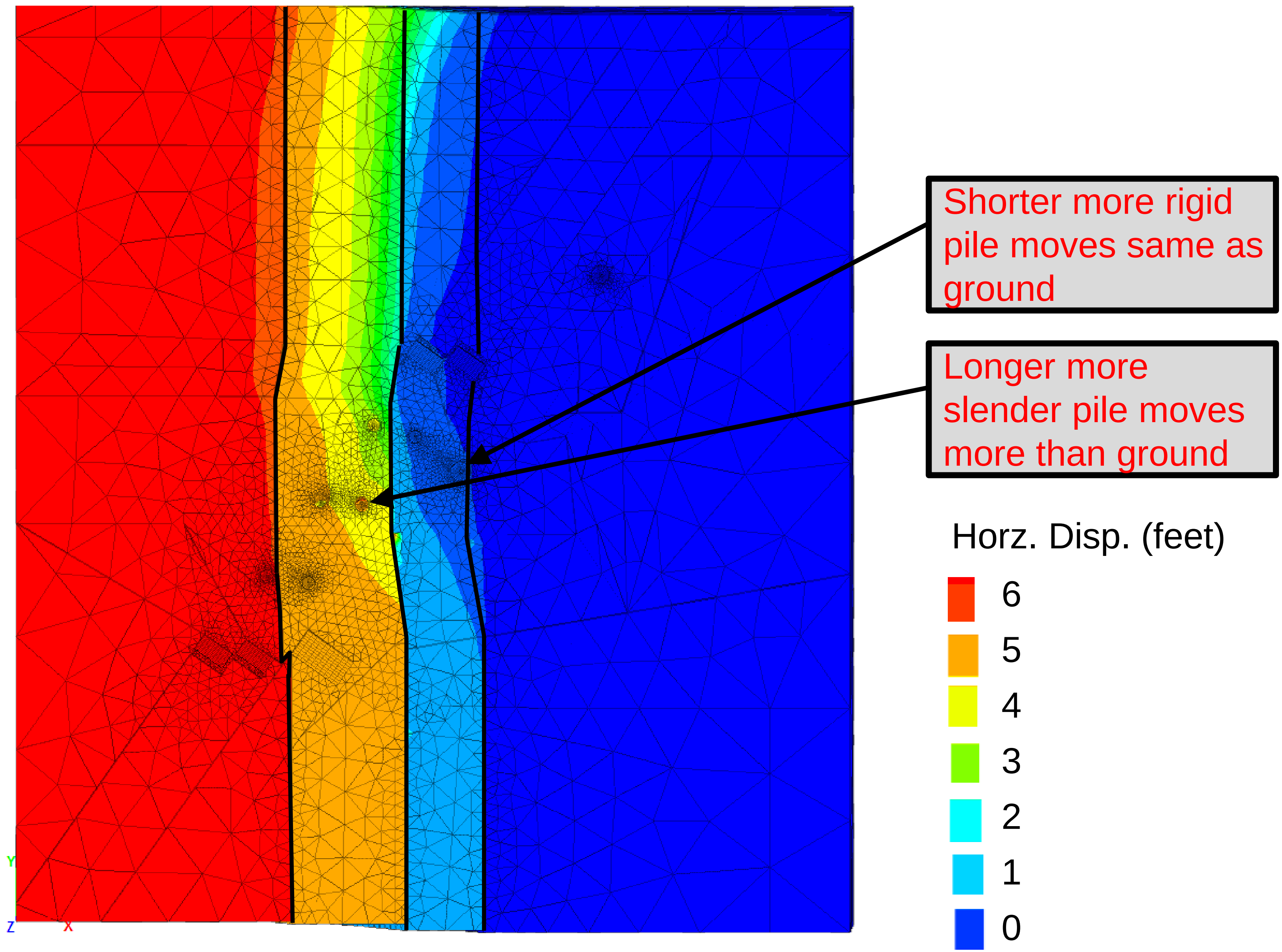


Centrifuge test data from Loli et al. (2009)

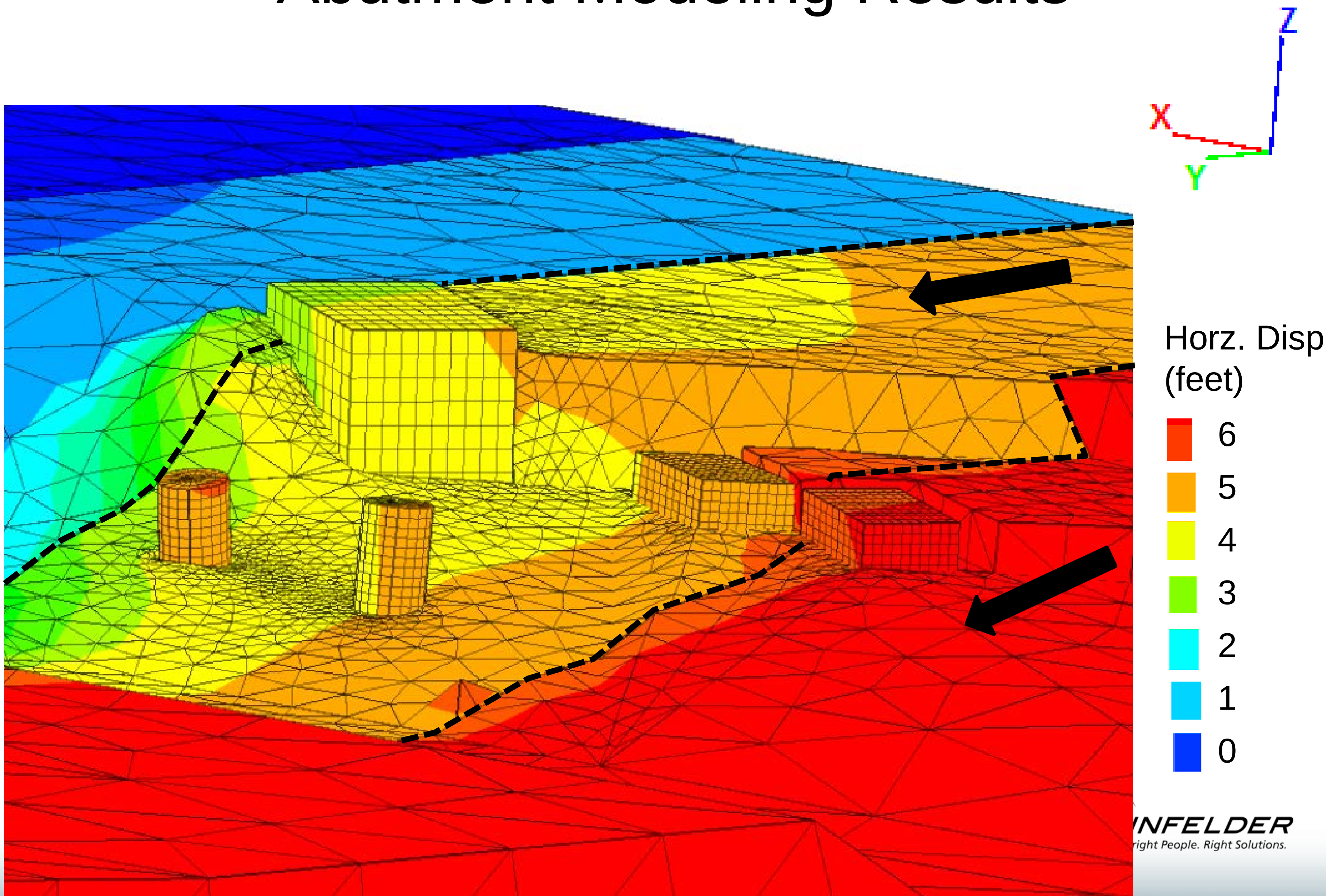


Model simulation results

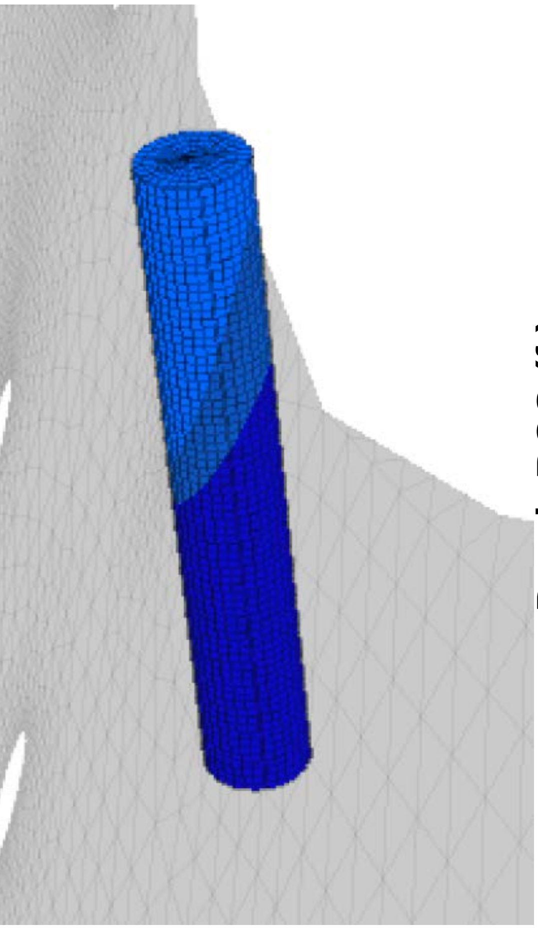
Modeling of Soil-Fault Foundation System

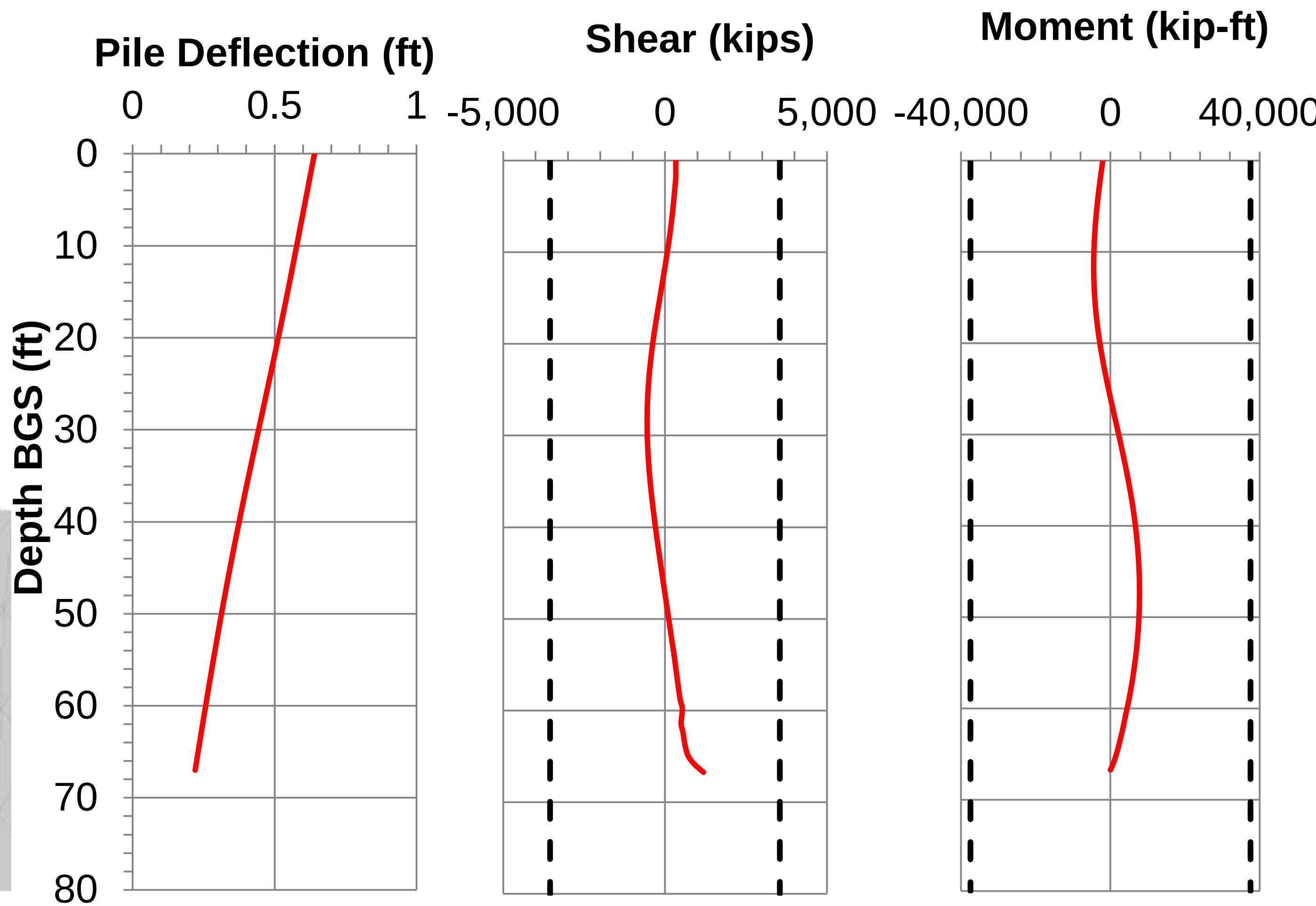


Abutment Modeling Results



Pile Performance





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Fault Rupture Design Displacements

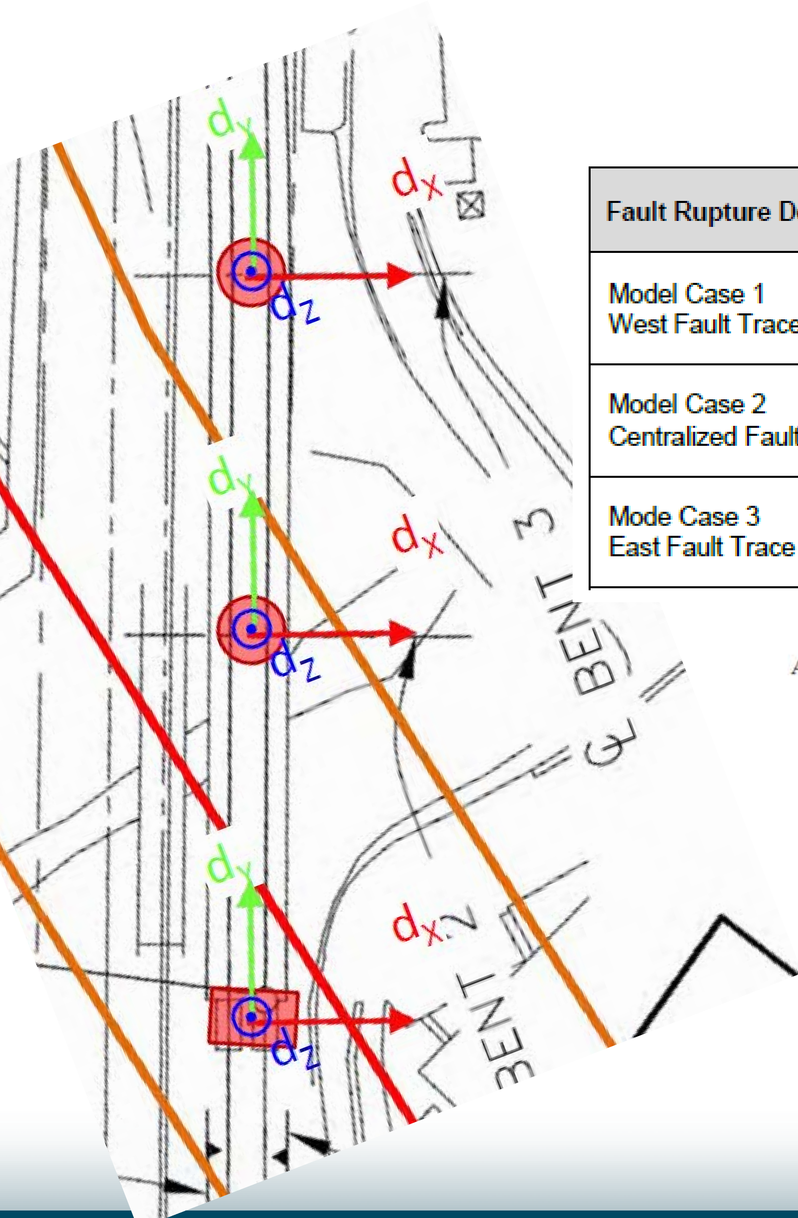
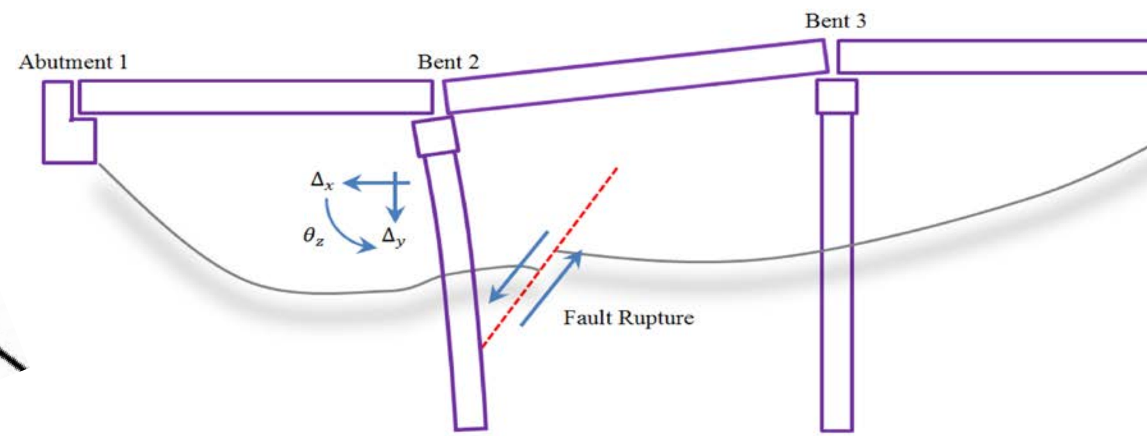


Table of Fault Rupture Design Scenarios

Fault Rupture Design Scenario	Foundation	d_x (feet)	d_y (feet)	d_z (feet)	θ_x (deg)	θ_y (deg)	θ_z (deg)
Model Case 1 West Fault Trace Location	Abutment 1	-2.3	4.1	0.5	-0.9	0	-1.5
	Bent 2	-0.1	0.3	0	-0.1	0	-0.1
	Bent 3	0	0	0	0	0	0
Model Case 2 Centralized Fault Trace Location	Abutment 1	-2.7	4.4	0.5	-0.1	0	-0.1
	Bent 2	-0.3	0.6	0	-0.4	0.1	-0.6
	Bent 3	0	0	0	0	0	0
Mode Case 3 East Fault Trace Location	Abutment 1	-3.0	5.0	0.6	0.1	-0.7	-1.1
	Bent 2	-0.7	1.1	0.1	0	0	-0.2
	Bent 3	-0.2	0.4	0	-0.1	0	-0.3



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Bridge Design

- Performance Objectives:
  1. Performance Level (No collapse)
     - Higher Level Project-Specified Ground Motion (Caltrans Design Spectrum)
  2. Service Level (Minimally serviceable to unserviceable after event)
     - Lower Level Project-Specified Ground Motion

Bridge Design

- Bridge Demand:

$$u_{ot} = u_{os} + u_{od}$$

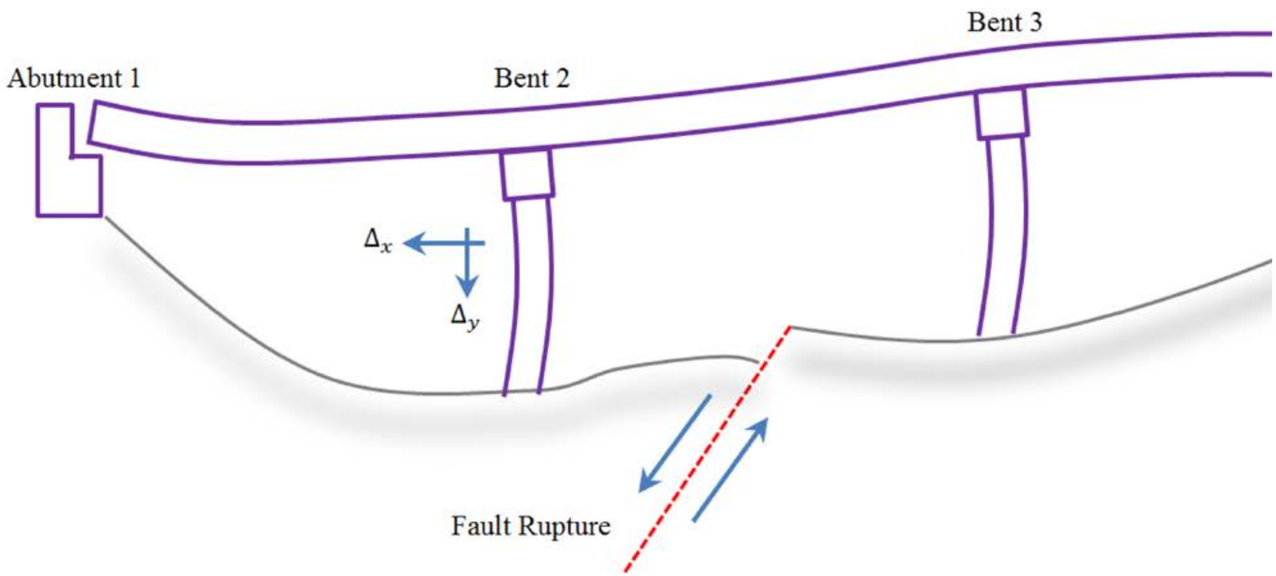
Peak Seismic Response of the Bridge

Peak Quasi-Static Demand

Peak Dynamic Demand

Bridge Design

- Bridge Alternatives



Deformed Shape of a Continuous Bridge Due to Surface Fault Rupture (Integral Bent Cap)

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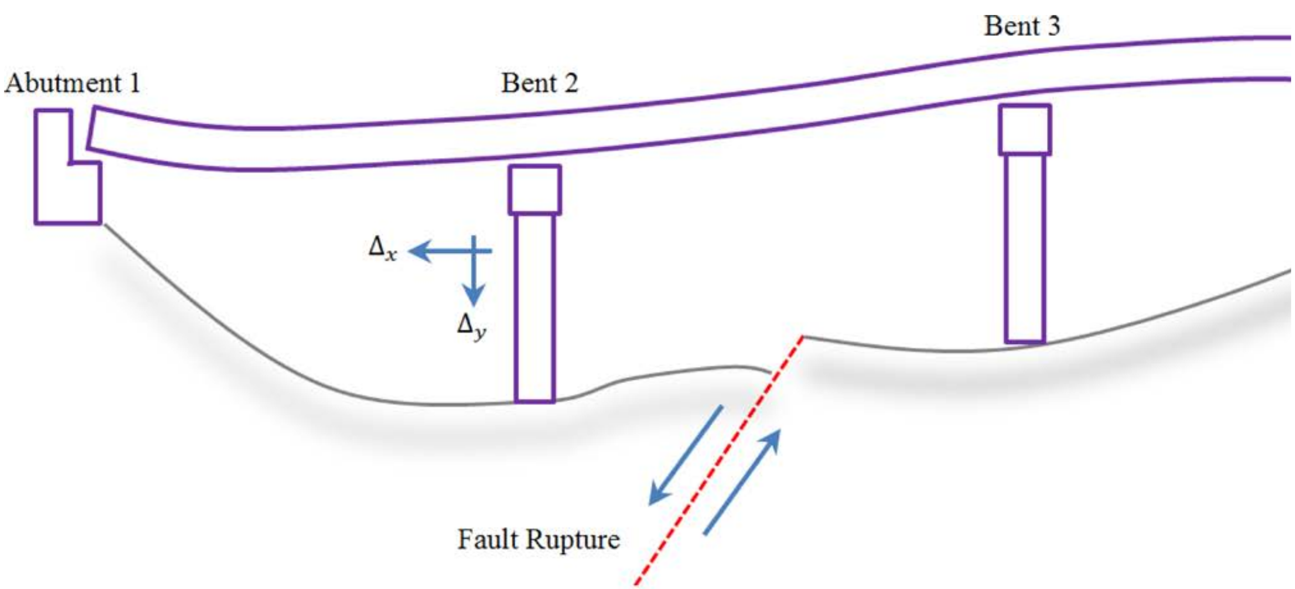
Bridge Design

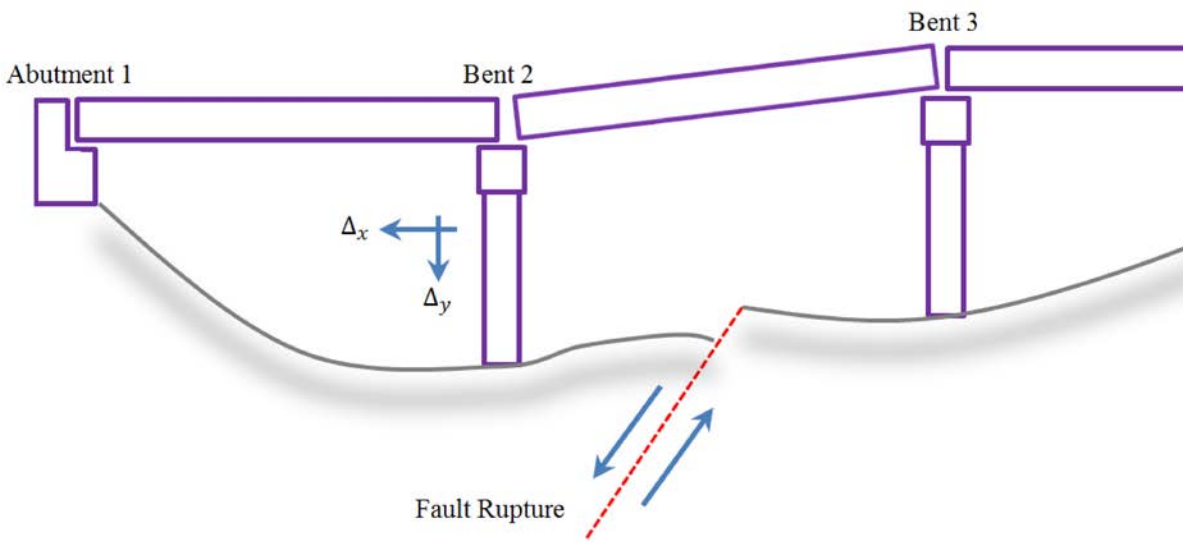
- Bridge Alternatives



Deformed Shape of a Continuous Bridge Due to Surface Fault Rupture (Dropped Bent Cap)

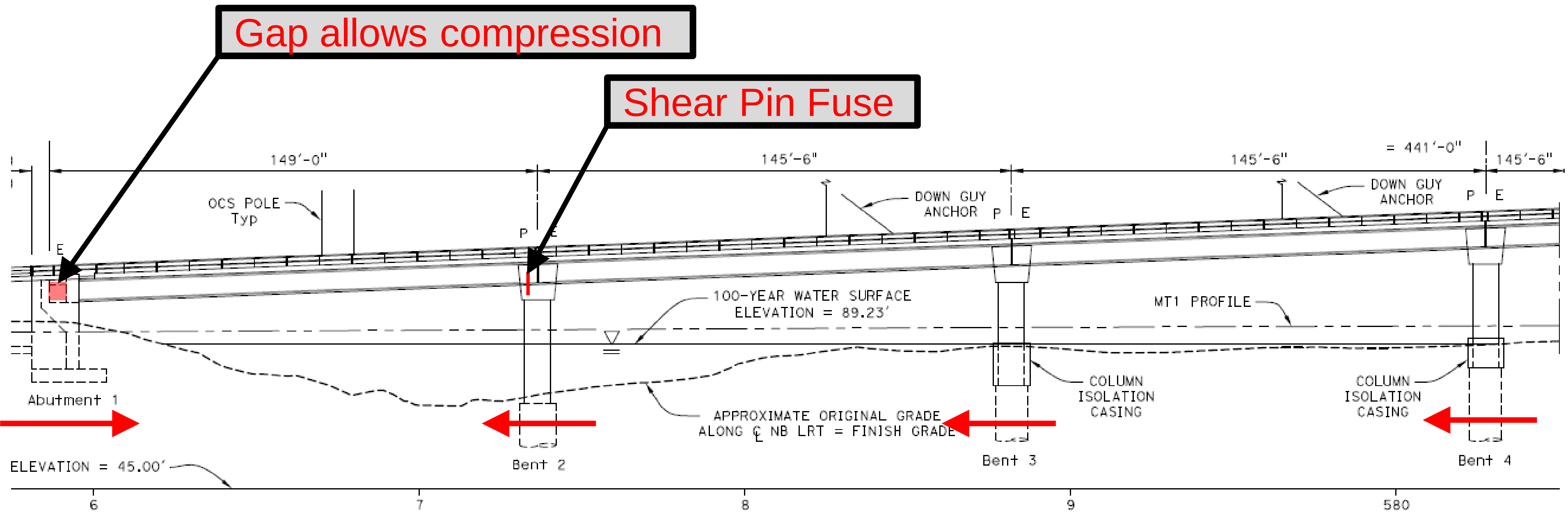
Bridge Design

- Bridge Alternatives



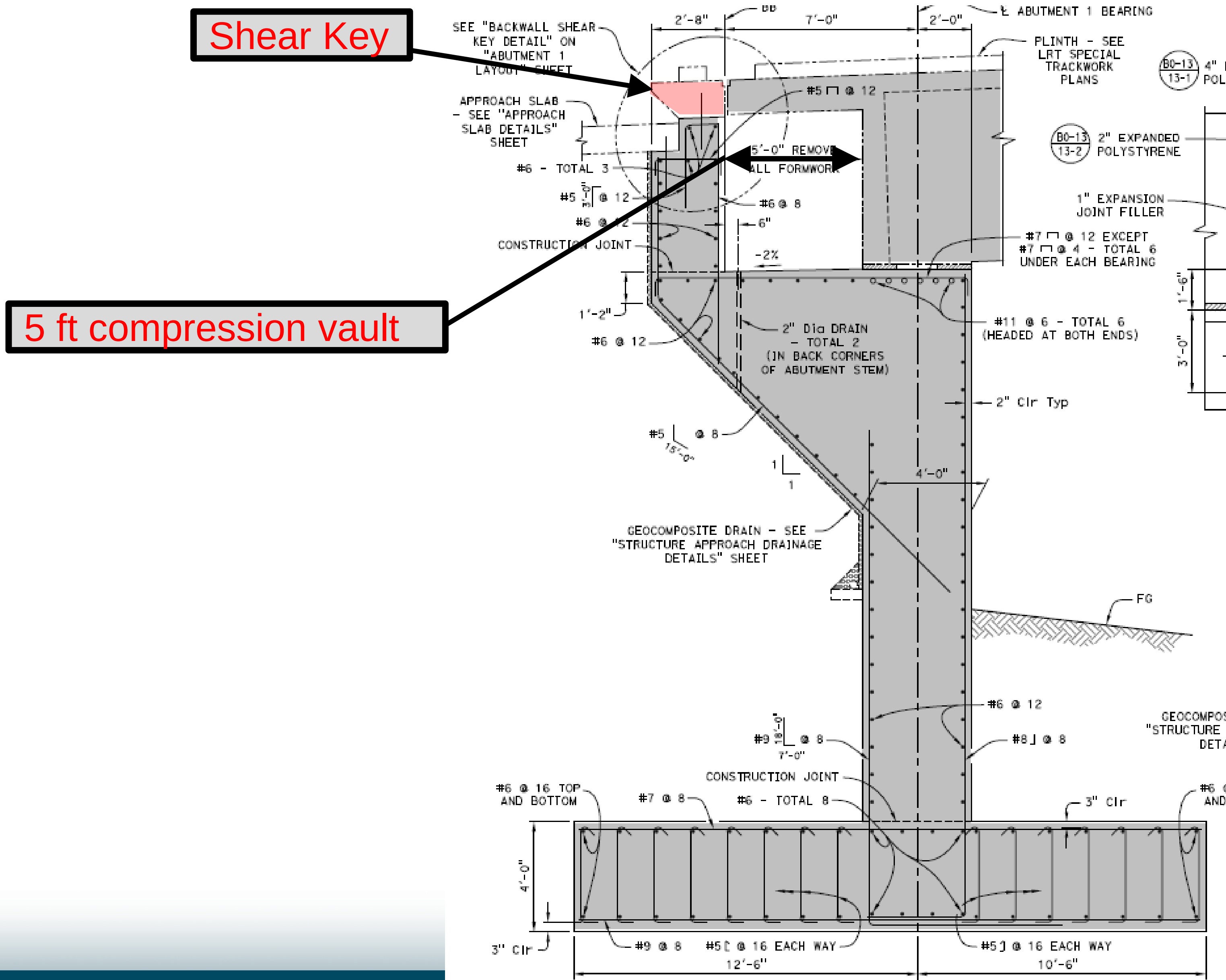
Deformed Shape of a Simply Supported Bridge Due to Surface Fault Rupture

Bridge Design

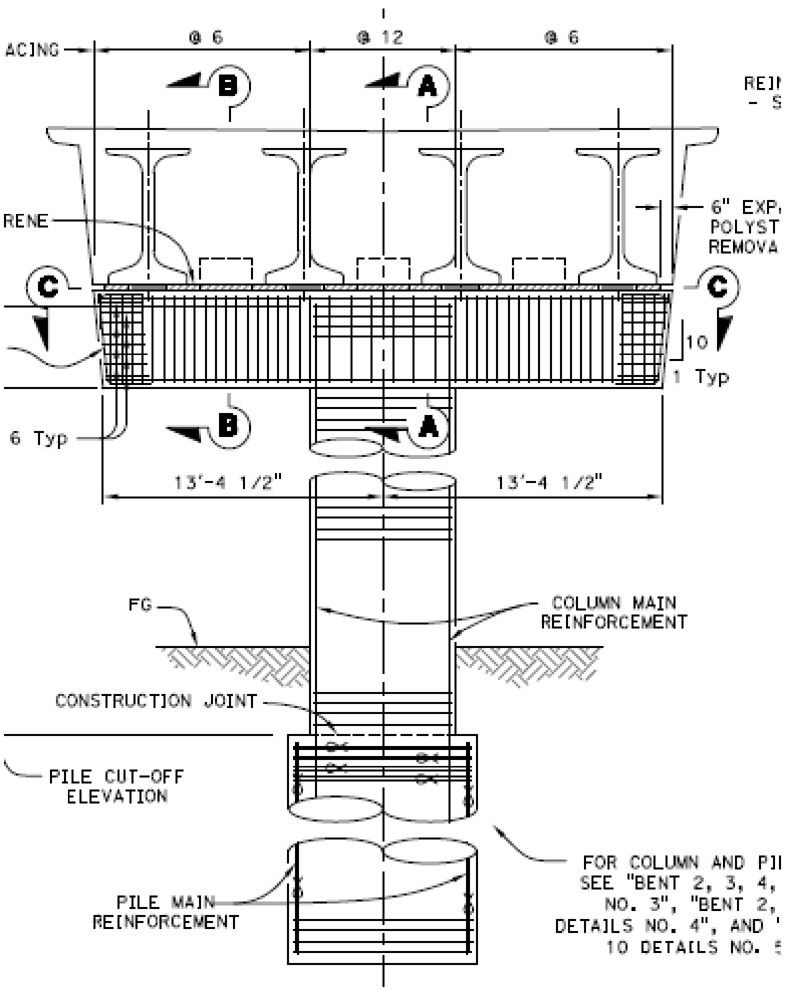


- Simple spans with pre-cast girders
- Widened seats
- Articulation
- Compression: gap at Abut + Pin Fuse at B2

Abutment Design



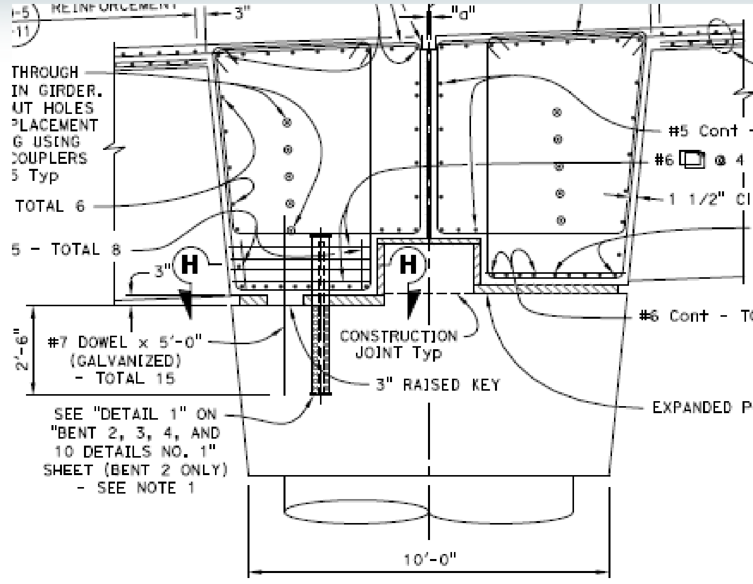
Details at Bent 2



NOTE: Bent 10 shown, Bents 2, 3, and 4 similar.

ELEVATION

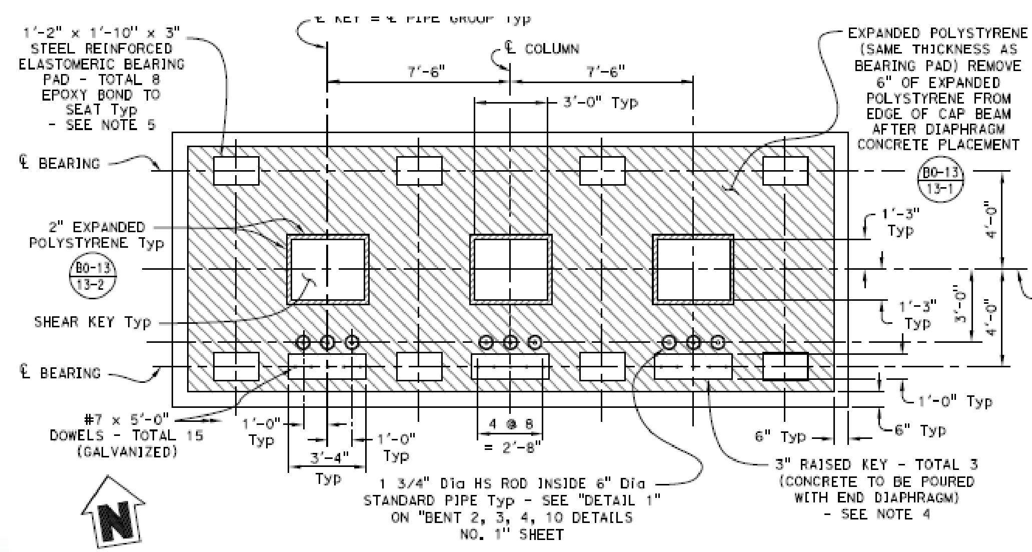
1/4" = 1'-0"



NOTE: Bent 2 shown, Bents 3, 4, and 10 similar, see Note 1.

SECTION G-G

1/2" = 1'-0"



SECTION C-C AT BENT 2

3/8" = 1'-0"

Conclusions

- Surface fault rupture hazard assessment and mitigation requires multi-discipline approach
- Translation of hazard into design scenarios requires engineering insight and judgment
- Foundations intersected by faults can be designed for ductile behavior and to perform satisfactorily despite severe fault load demands
- Bridge can be designed for no-collapse using articulation and ductility, but severe damage should be expected.

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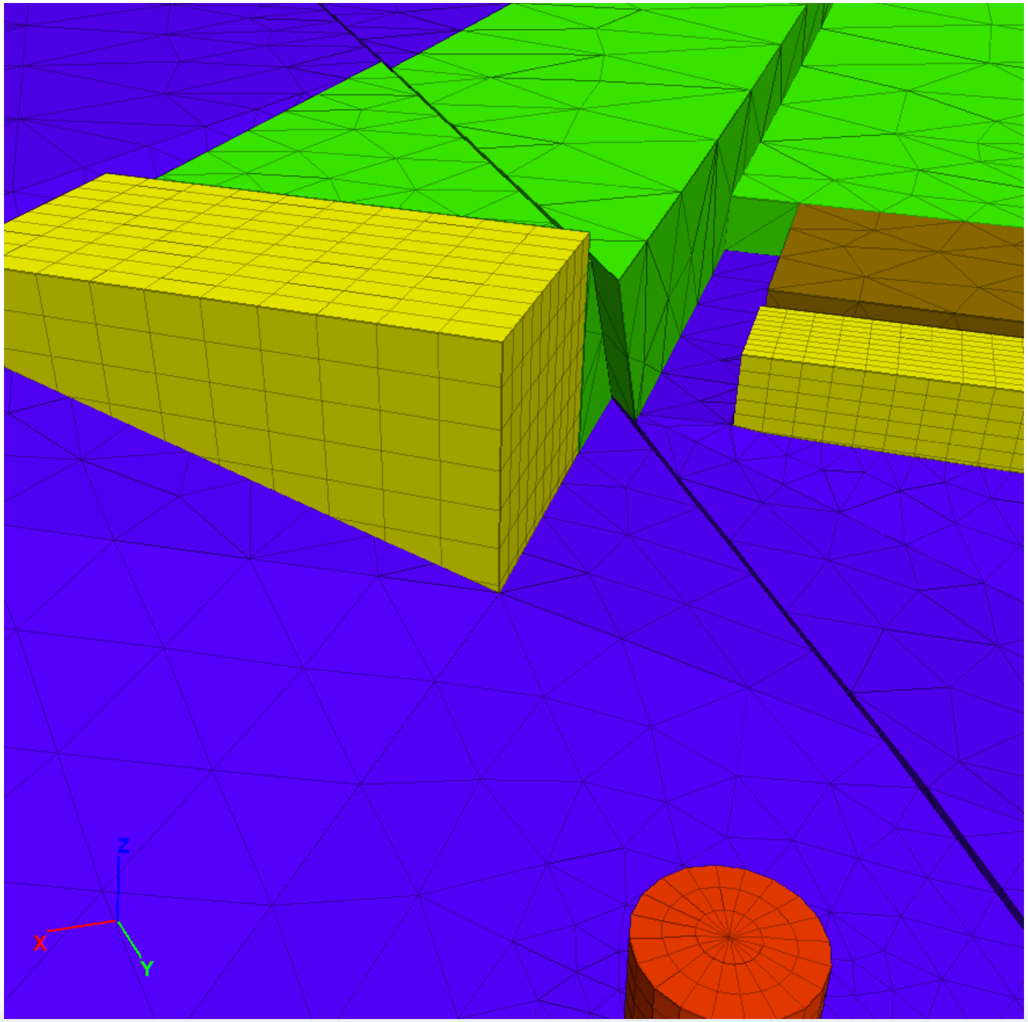
THANK YOU



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