ENGINEERING IMPLEMENTATION OF THE RESULTS OF A FAULT DISPLACEMENT HAZARDS ANALYSIS

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Sponsored in part by the National Science Foundation
& Geotechnical Extreme Events Reconnaisssance (GEER)

Structures Undamaged, Functional, or Life-Safe After Faulting

Hazards of Ground Movements

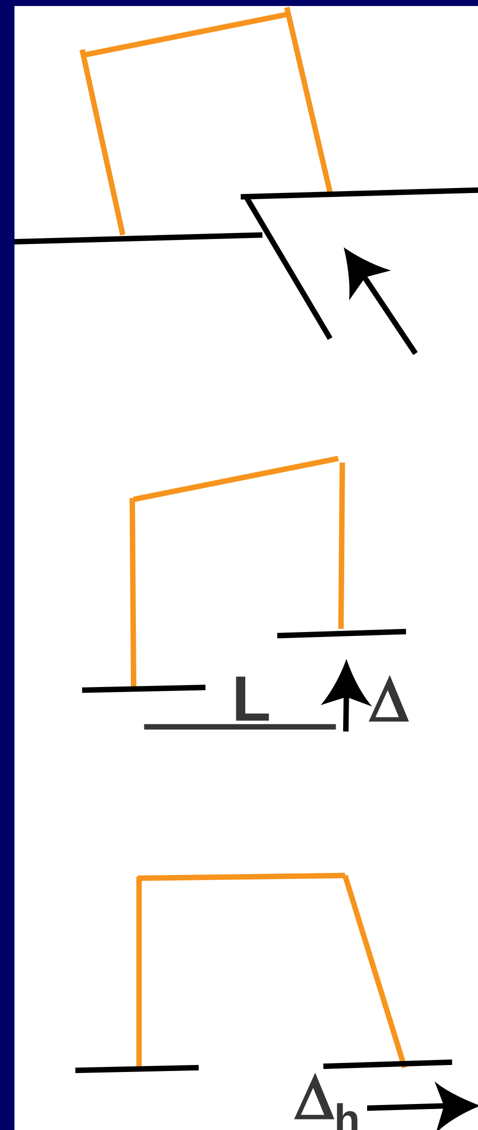
A. Shear Rupture

B. Angular Distortion

C. Extensional Strain

D. Tilt

E. Tectonic Subsidence



$\beta = \Delta / L$

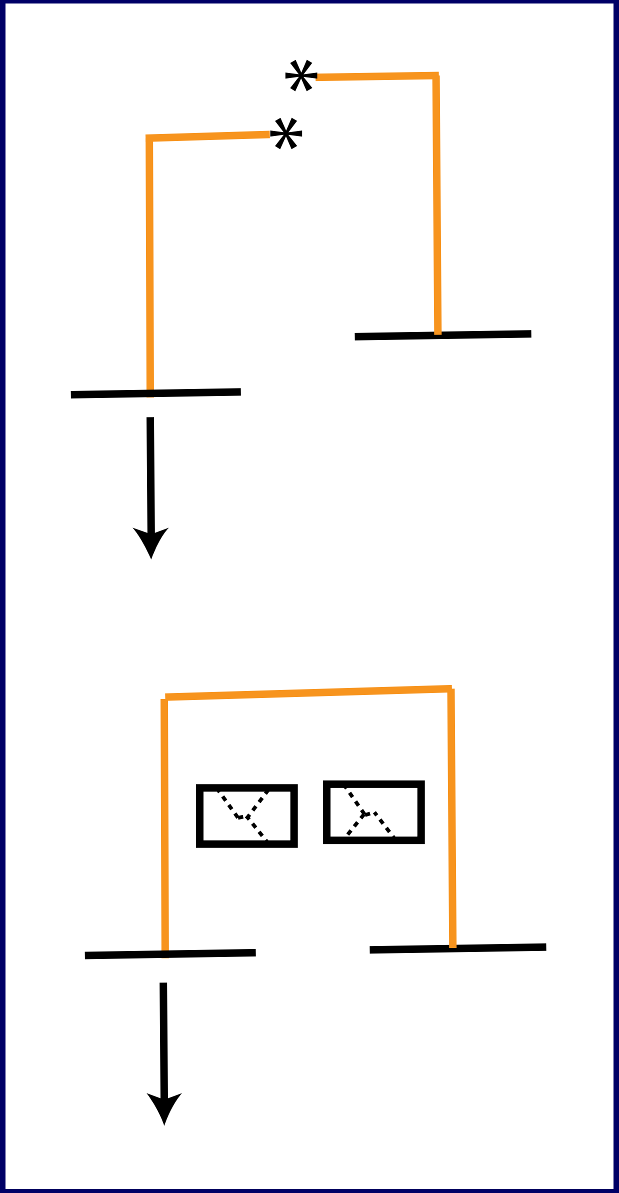
$\varepsilon_h = \Delta_h / L$

Consequences of Ground Movements

A. Structural Damage

B. Functional Damage

C. Architectural Damage



Tolerable Levels of Ground Movements

A. Conventional Construction: $\beta = 1/500$, $\Delta_t = 25$ mm

B. Post-Tensioned Slab Residential: $\beta = 1/360$, $\Delta_t = 40$ mm

C. Liquefaction-Induced Settlement: $\Delta_t = 100$ mm

(with "structural mitigation" CGS SP-117A, Youd 1989)

D. Liquefaction-Induced Horz. Movement: $\Delta_t = 300$ mm

(with "structural mitigation" CGS SP-117A, Youd 1989)

NOT $\Delta_t = 0$ mm

Surface Fault Rupture Damage to Homes in South Napa EQ

Documented 27 homes affected by surface rupture

Average observed deformation: 100 to 125 mm

Key Observations:

- No life safety issue resulted from surface faulting
- Unreinforced concrete slabs cracked
- Reinforced slabs slid uniformly or tilted
- Structures on pier foundations more heavily damaged
- Seismically retrofit homes/new construction performed best

Damage to structure

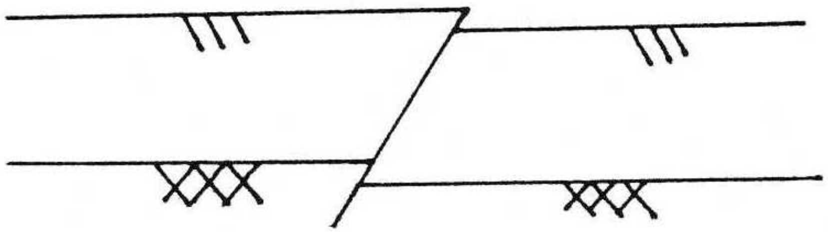
Cracked garage slab

Pushed off foundation

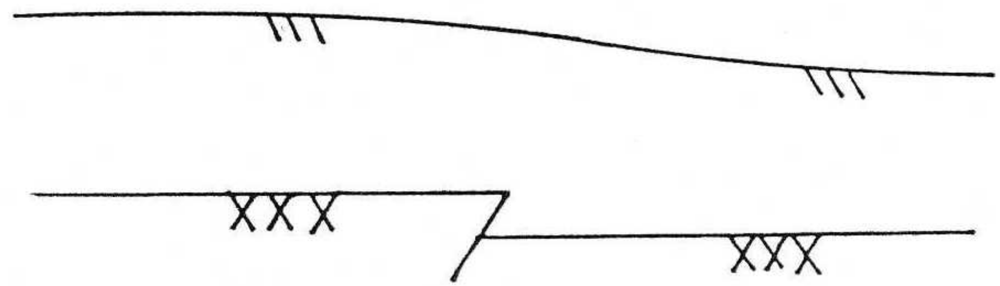
Rupture through piers

Moorpark Development Project, California

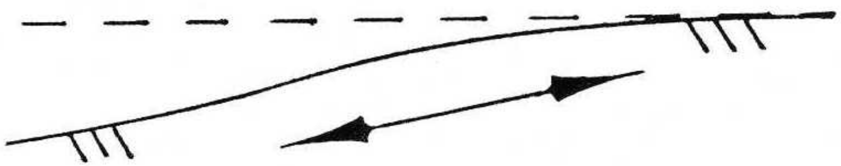
(Bray 2001)



(A) Distinct Shear Rupture **- Not Allowed**



(B) Differential Settlement **$\beta < 1/360$**

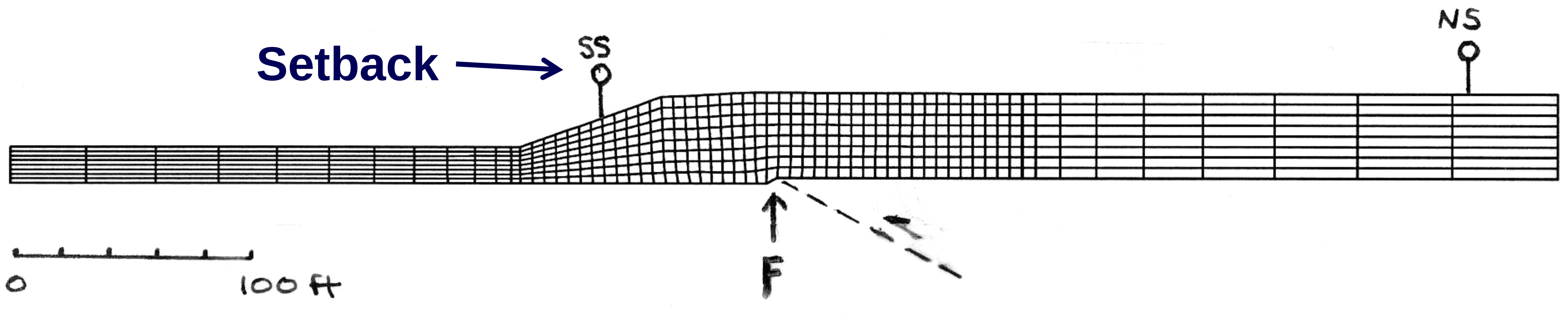


(C) Tensile Strains **$\varepsilon_h < 0.3\%$**

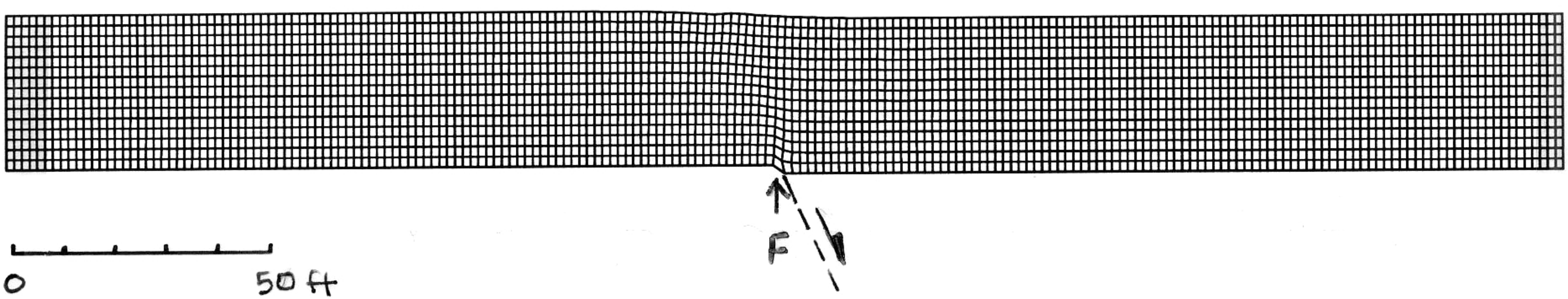
Decouple slab with plastic slip layer

GROUND DEFORMATION DESIGN CRITERIA FOR BUILDING AREAS

Moorpark Development – Surface Fault Rupture Evaluation
(Bray 2001)

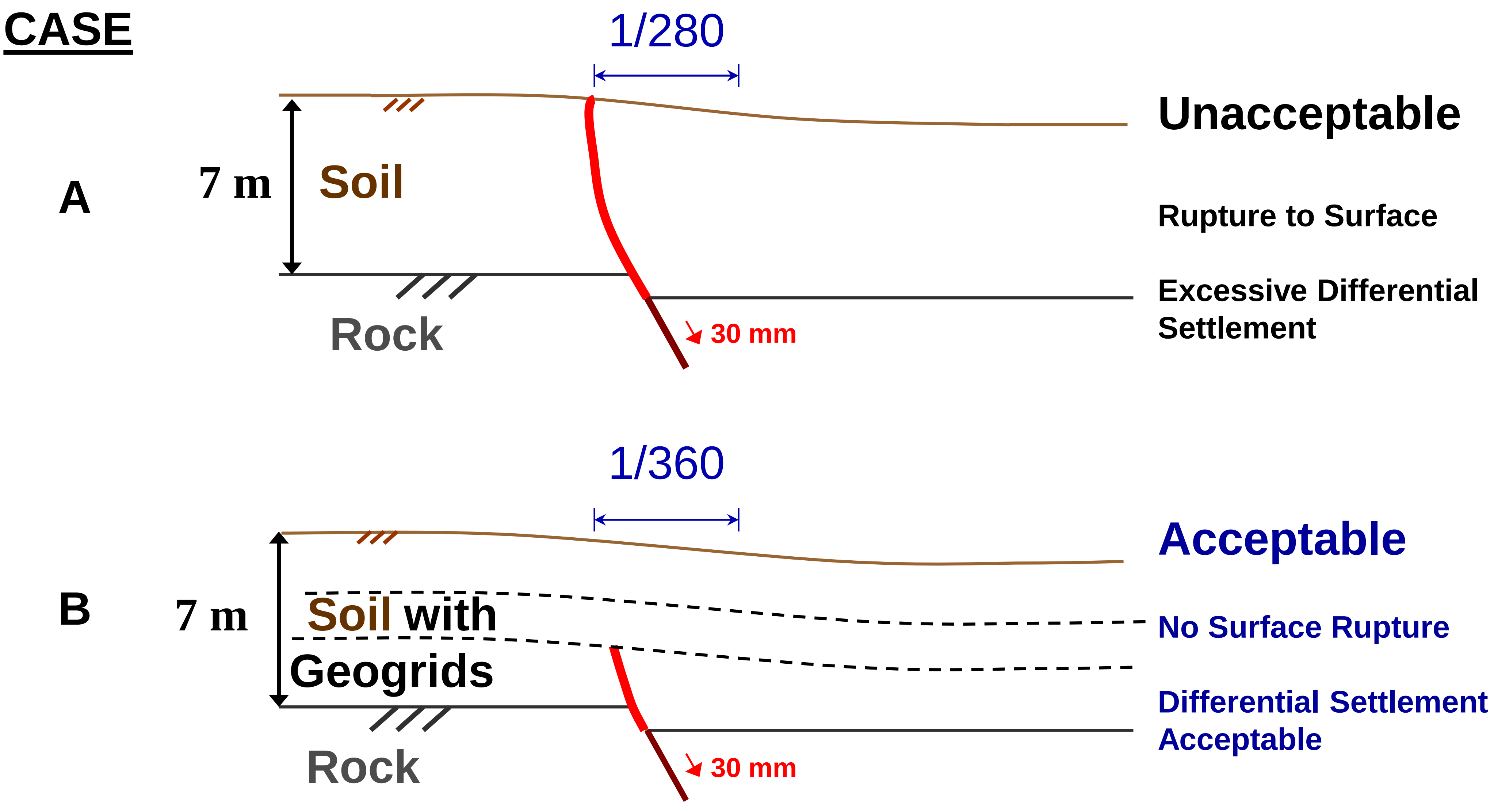


Primary Active Faults with > 100 mm of potential offset



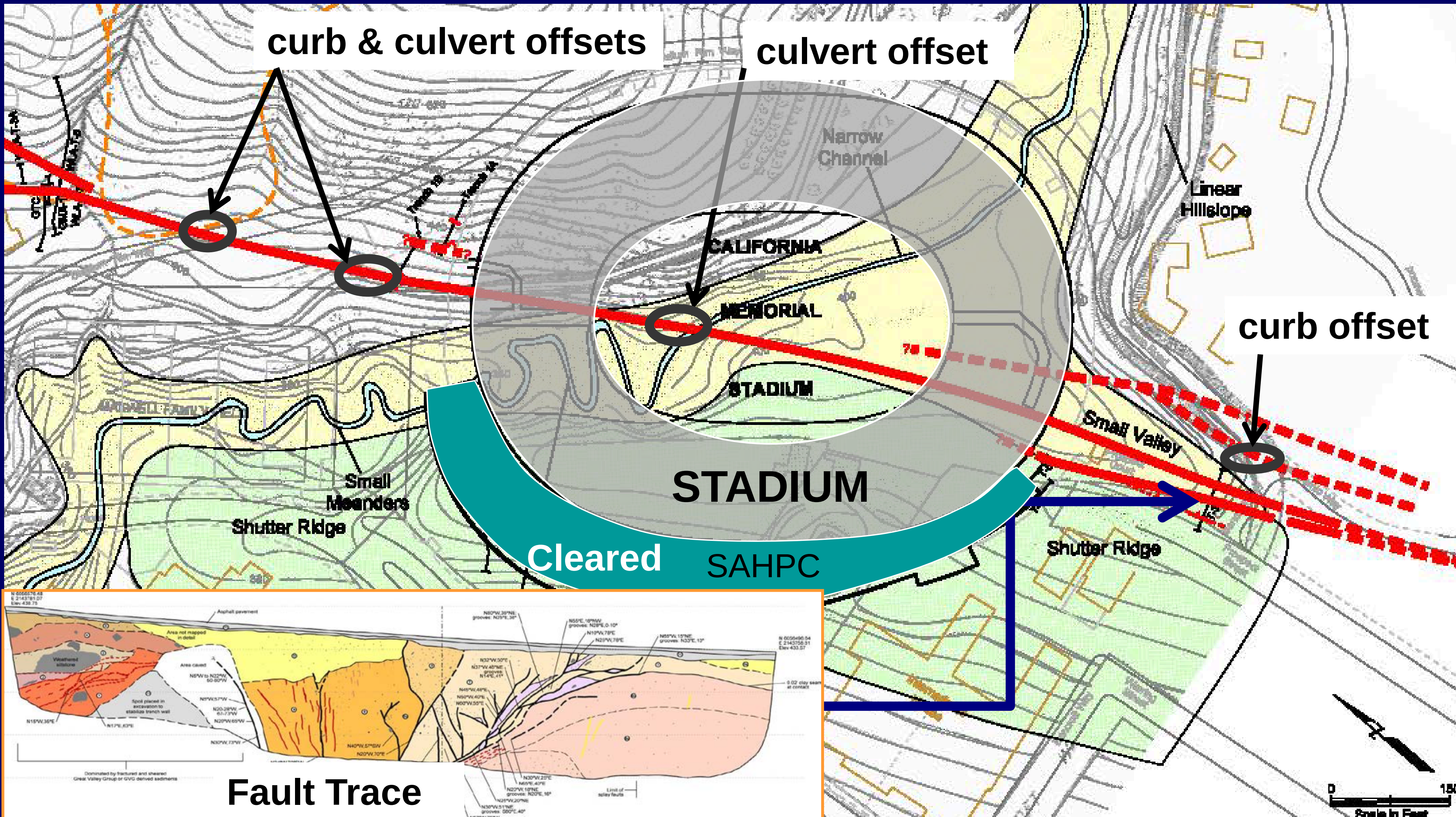
Bending Moment Active Faults with < 40 mm of potential offset

RESULTS OF NUMERICAL ANALYSIS (Bray 2001)



CHARACTERIZING HAYWARD FAULT

AMEC Geomatrix (Wells , Swan, et al.)



UCB Seismic Review Committee(Bray, Sitar, Comartin, Moehle, et al.)   Forell/Elsesser Engineers, Inc. (Friedman, Vignos, et al.)

CHARACTERIZING HAYWARD FAULT

Fault Rupture Design Guidance

AMEC Geomatrix (Wells, Swan, et al.)

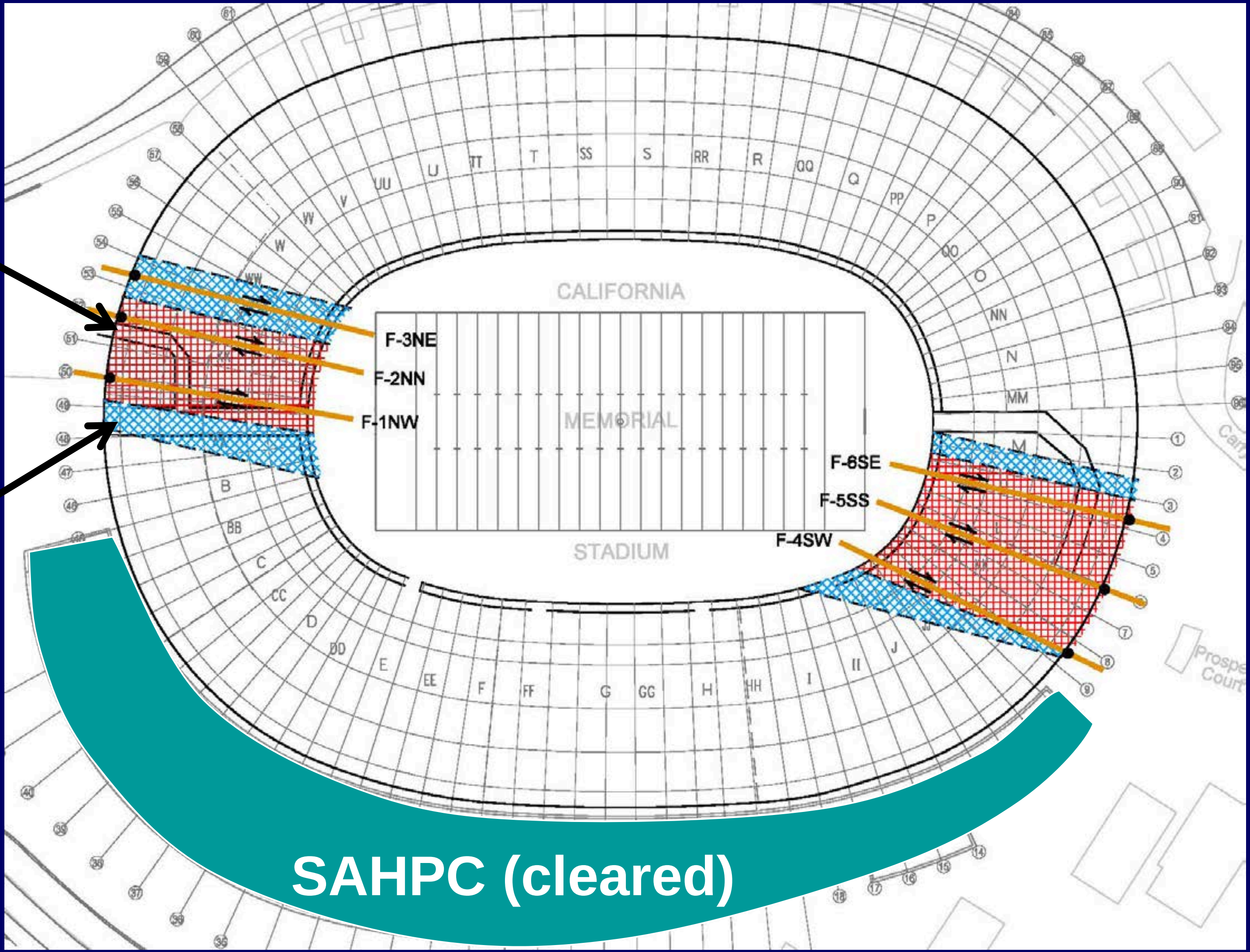
Primary:

0.9 – 1.9 m H

0.3 – 0.6 m V

Secondary:

< 0.3 m H



UCB Seismic Review Committee

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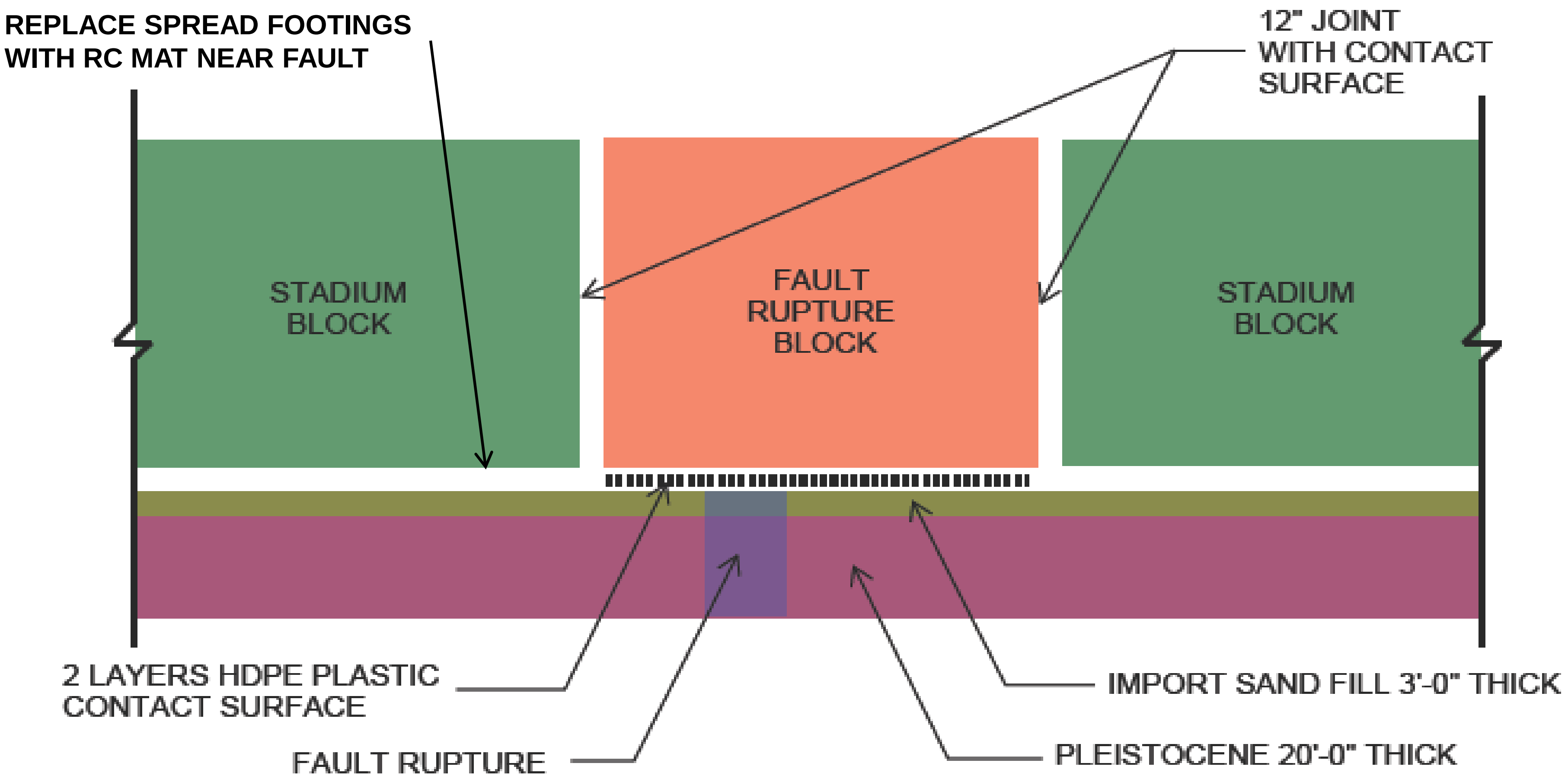
Engineering Mitigation of Fault Displacement

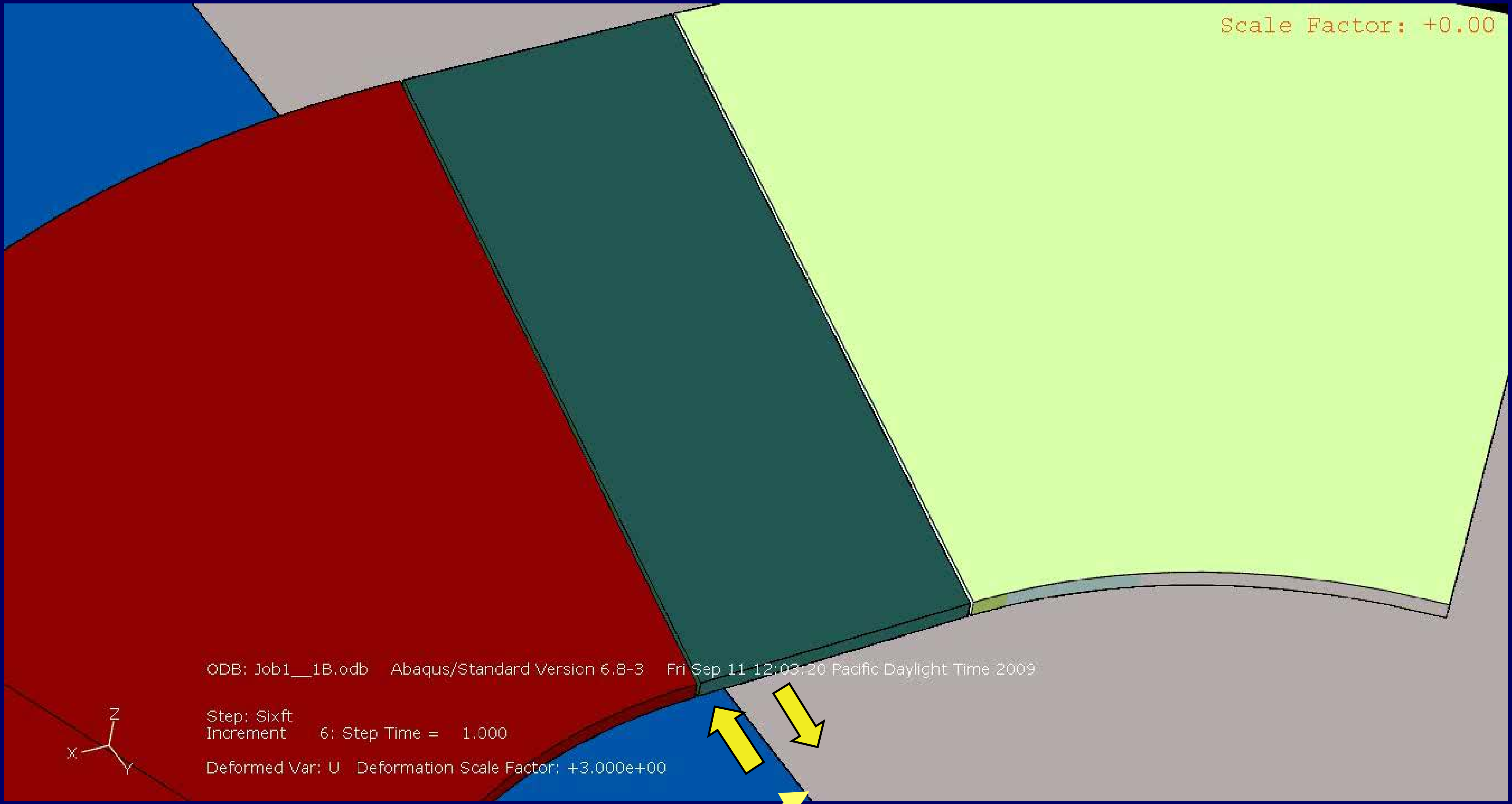


UCB Seismic Review Committee
(Bray, Sitar, Comartin, Moehle, et al.)

AMEC Geomatrix
(French et al.)

Forell/Elsesser Engineers, Inc.
(Friedman, Vignos, et al.)

Modeling of the Effects of Surface Faulting



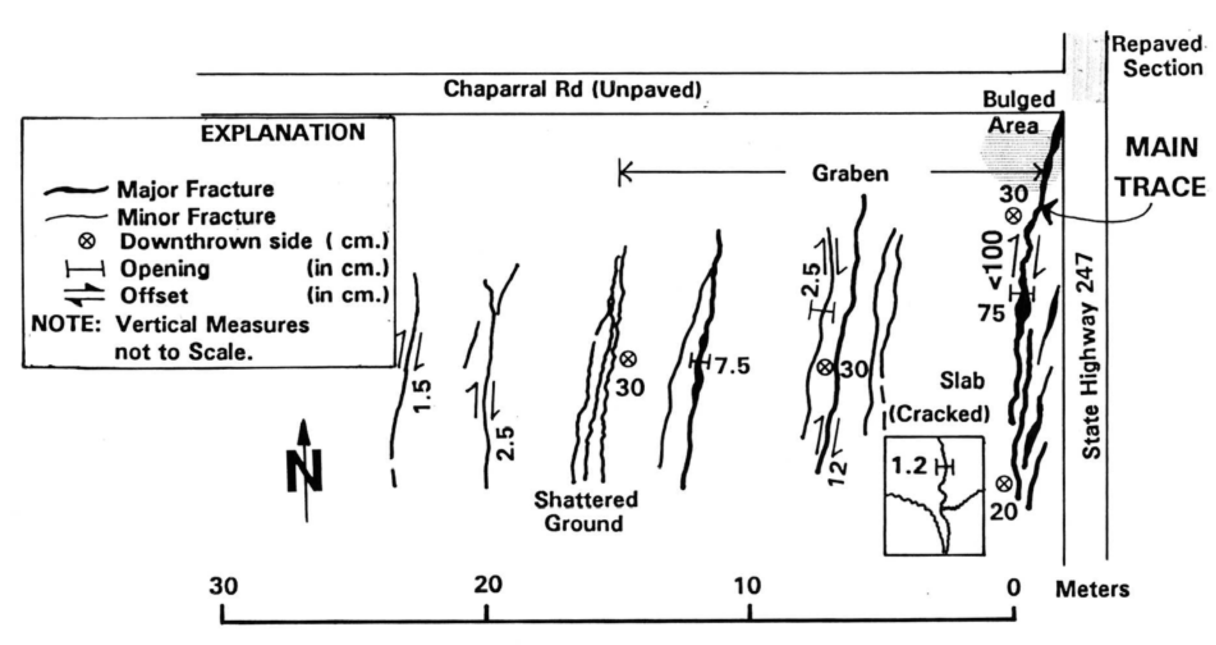
Fault

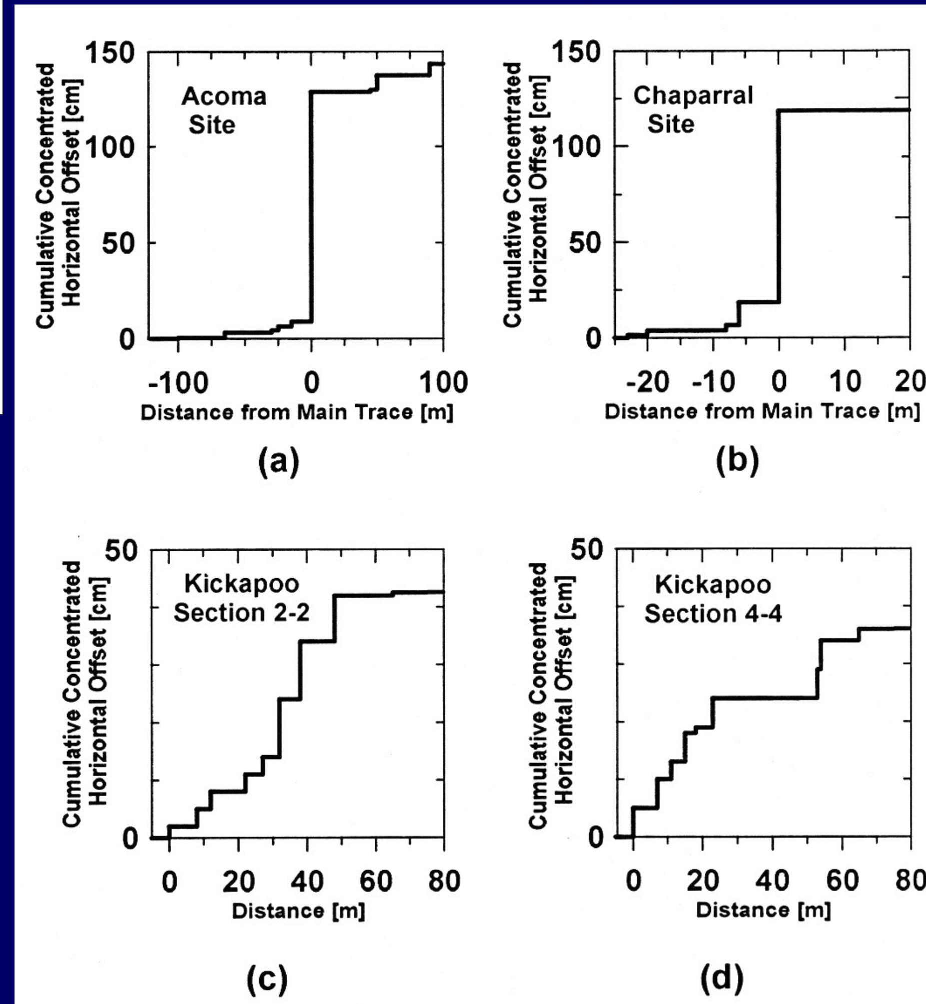
Forell/Elsesser Engineers, Inc.
(Friedman, Vignos, et al.)

Surface Rupture Characteristics Depend On:

- fault type
- fault geometry
- amount of fault displacement
- maturity of fault
- earth material over fault
- structure and its foundation

1992 Landers Earthquake





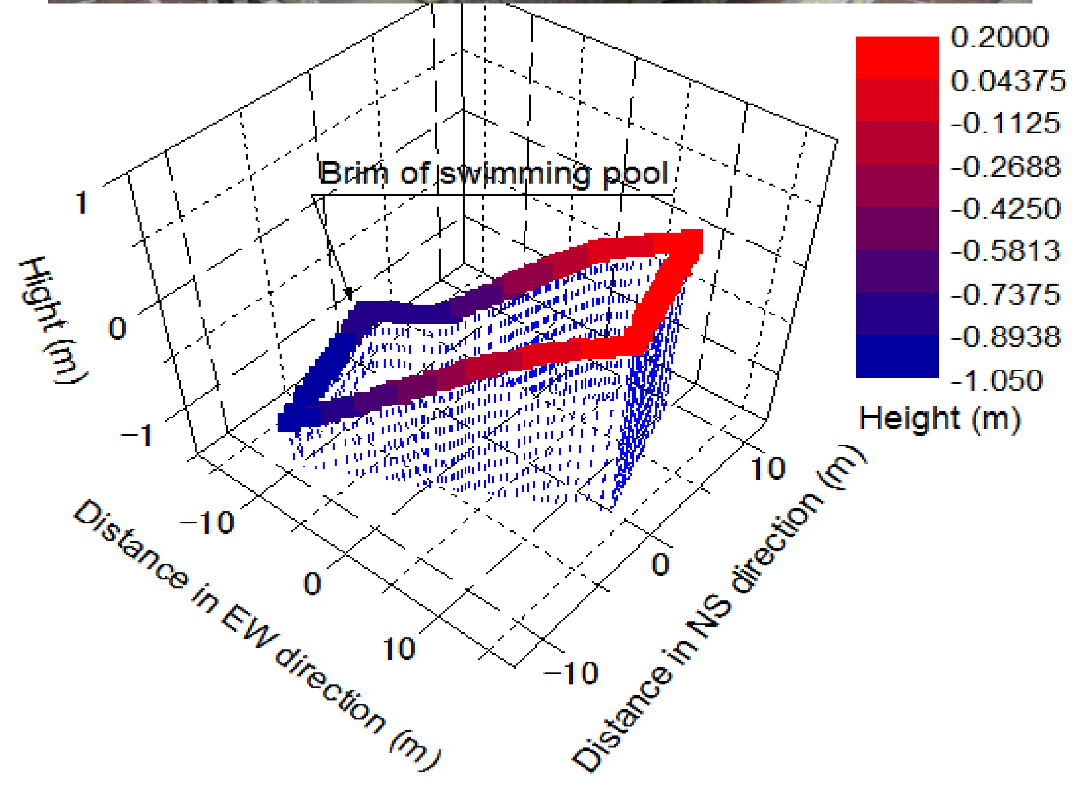
Lazarte, Bray & Johnson (1994)

Broad Area of Building Damage on Hanging Wall of Reverse Fault

Not on footwall

1999 Chi-Chi EQ

TABITO MIDDLE SCHOOL

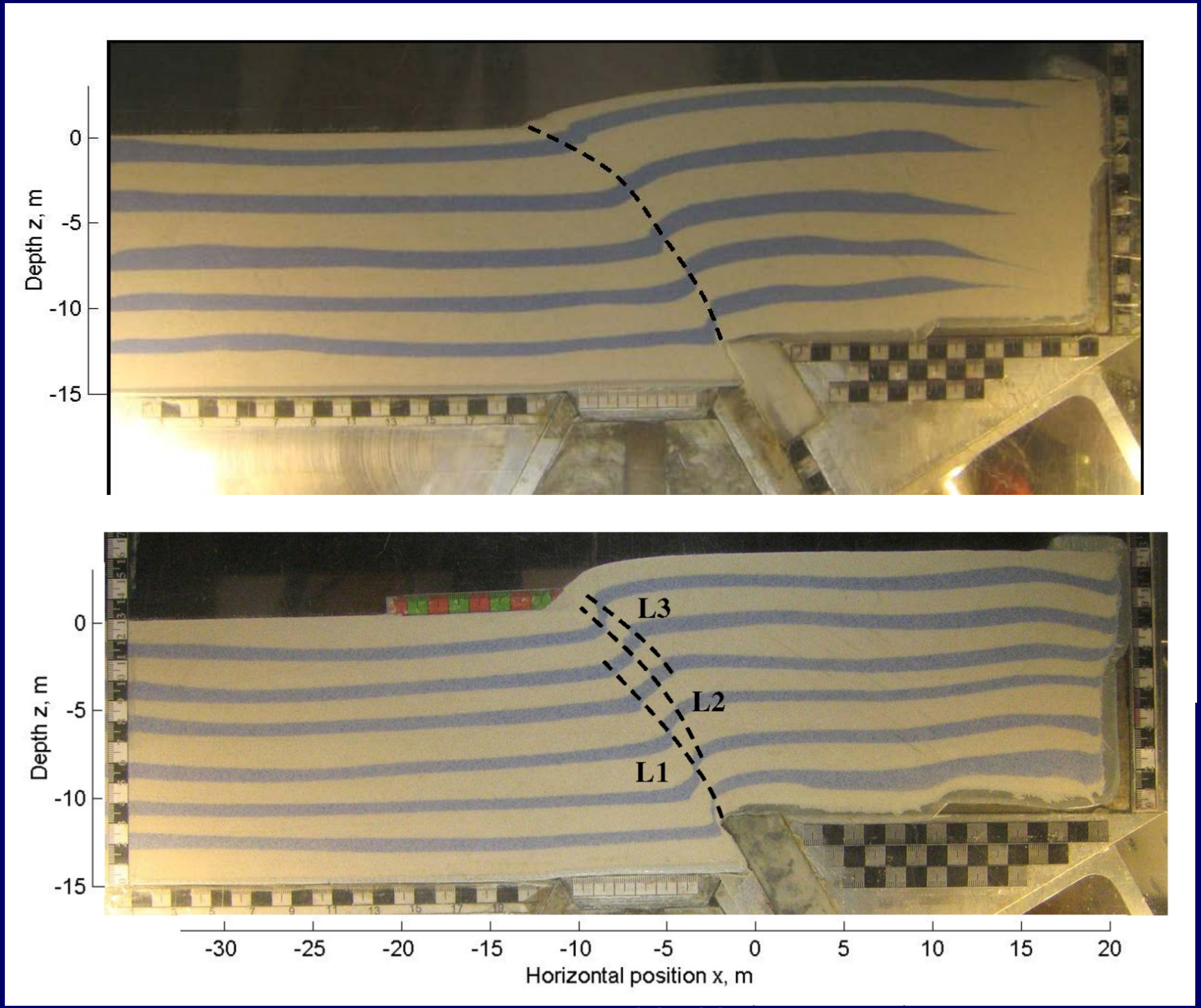


M_w 6.6 Hamadoori Aftershock of 4/11/11: Shionohira Normal Fault Displacement

Laser survey of the brim of the pool (Konagai, Bray, Streig, & others)

1.25 m vertical displacement between ends of pool

CENTRIFUGE TEST OF FAULT RUPTURE WITH AND WITHOUT MAT FOUNDATION (Davies et al. 2007)

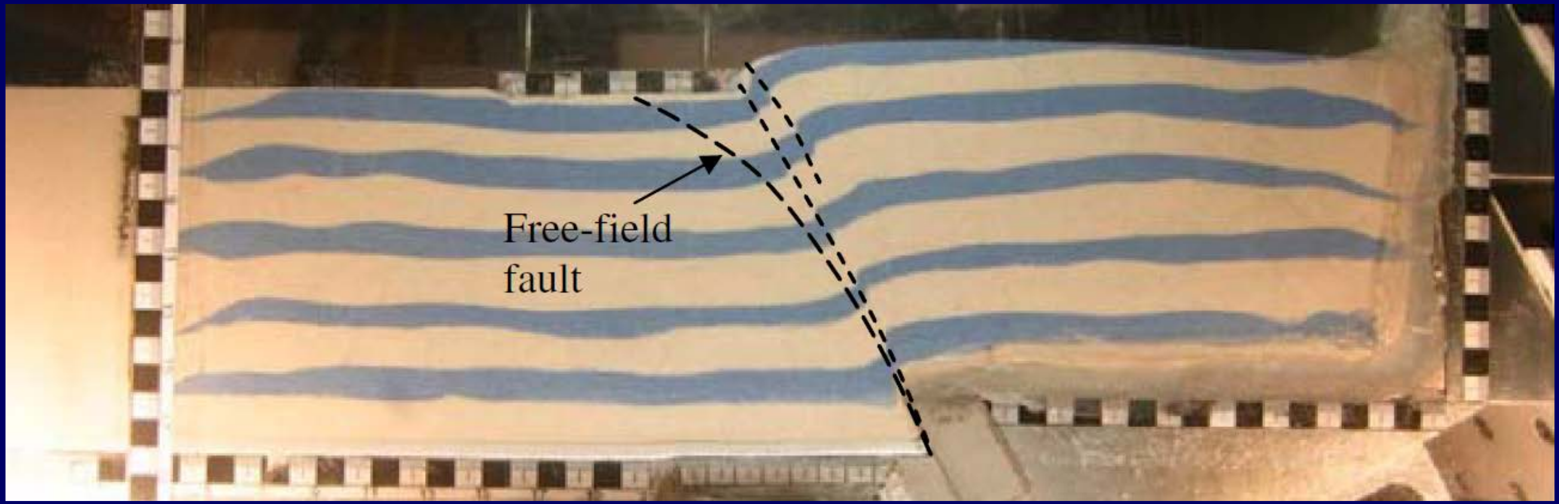


provided by Anastapolous & Gazetas

WEIGHT OF MAT FOUNDATION EFFECTS (Davies et al. 2007)

Light Load:
q = 37 kPa

Heavy Load:
q = 91 kPa



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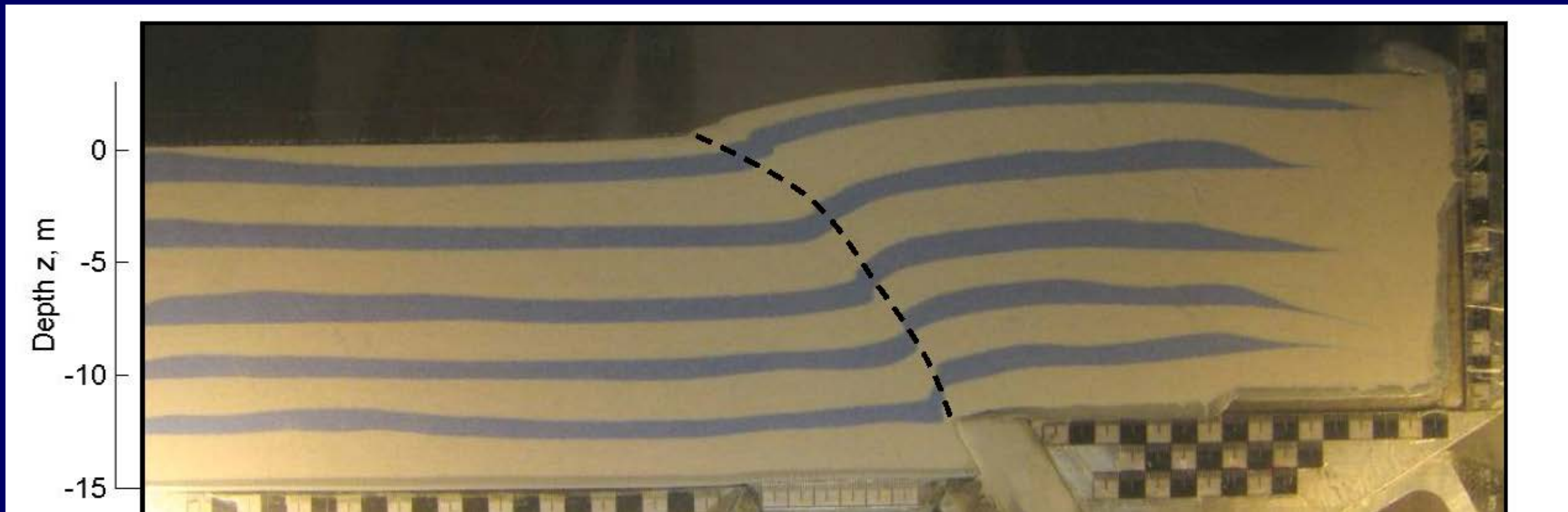
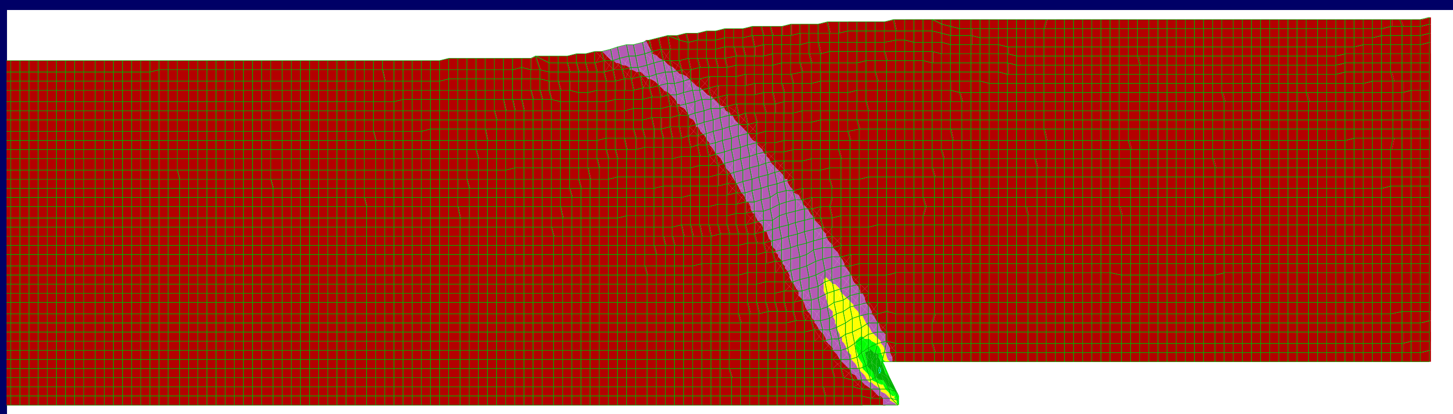
MODELING OF FAULT RUPTURE

Centrifuge Test: 60º Reverse Fault Uplift in Sand (Davies et al. 2007; Prototype Scale)

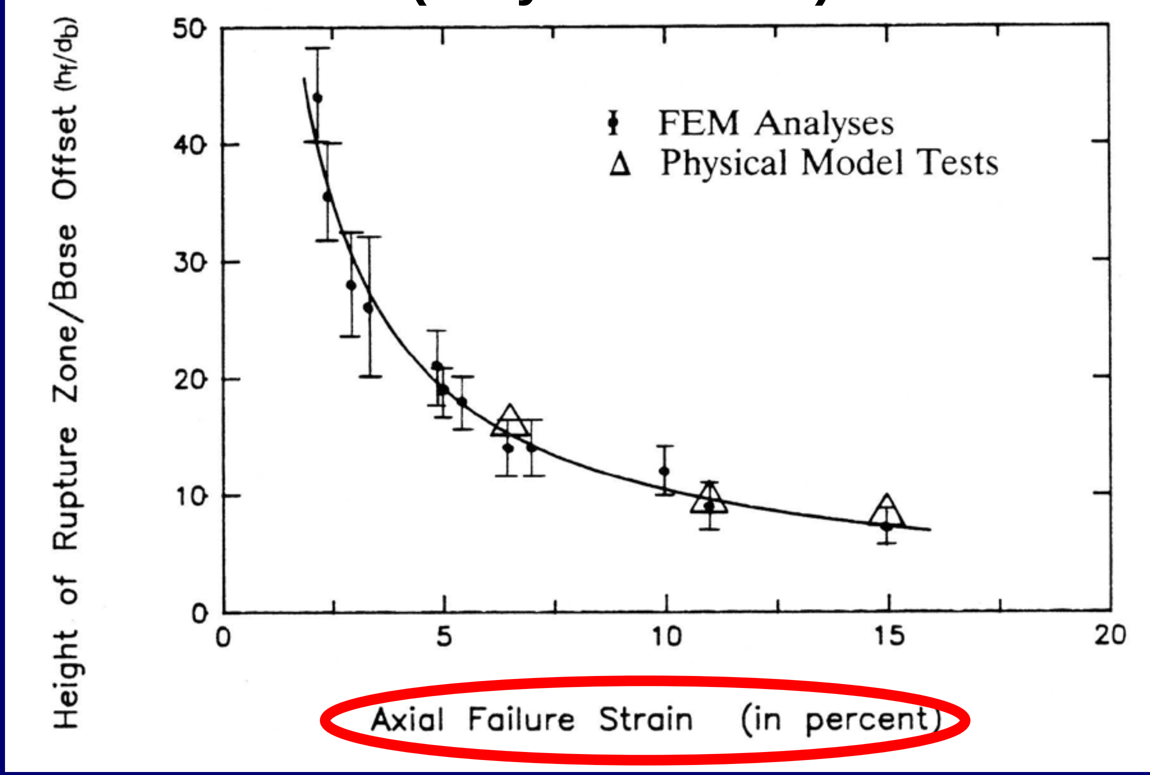


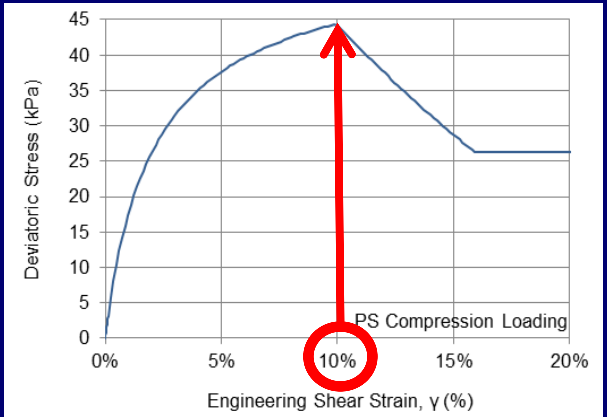


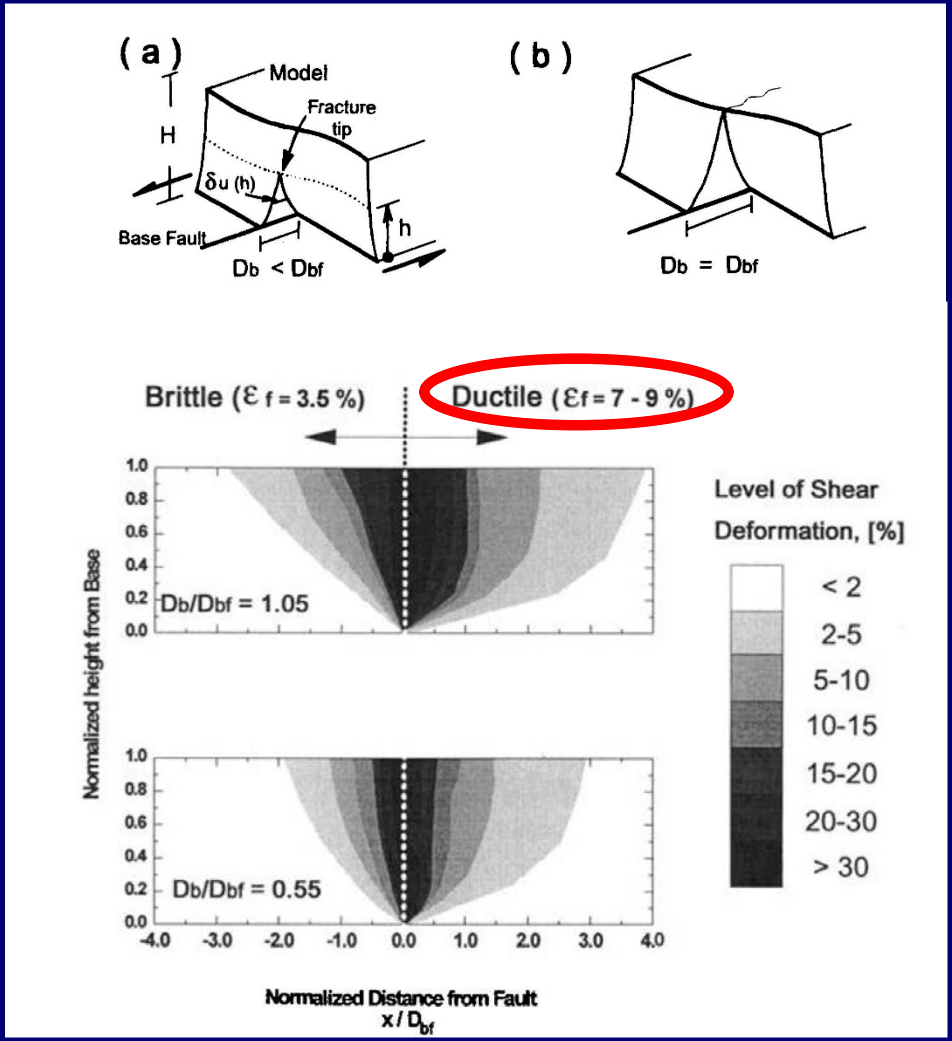
FLAC-2D / mod-UBCSAND Analysis: 60º Reverse Fault Uplift in Sand (Oettle & Bray 2013)

Importance of Failure Strain

(Bray et al. 1994)

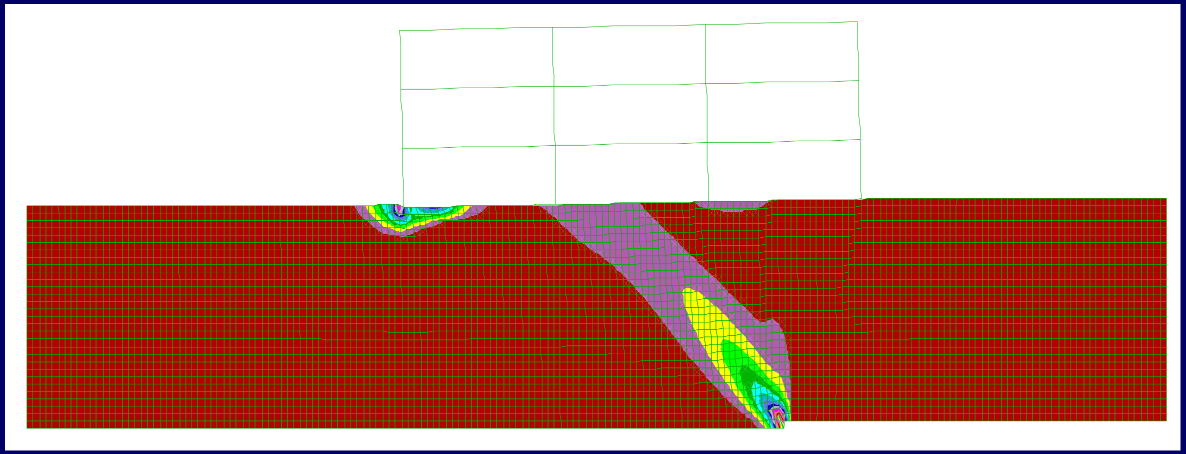






(Lazarte & Bray 1996)

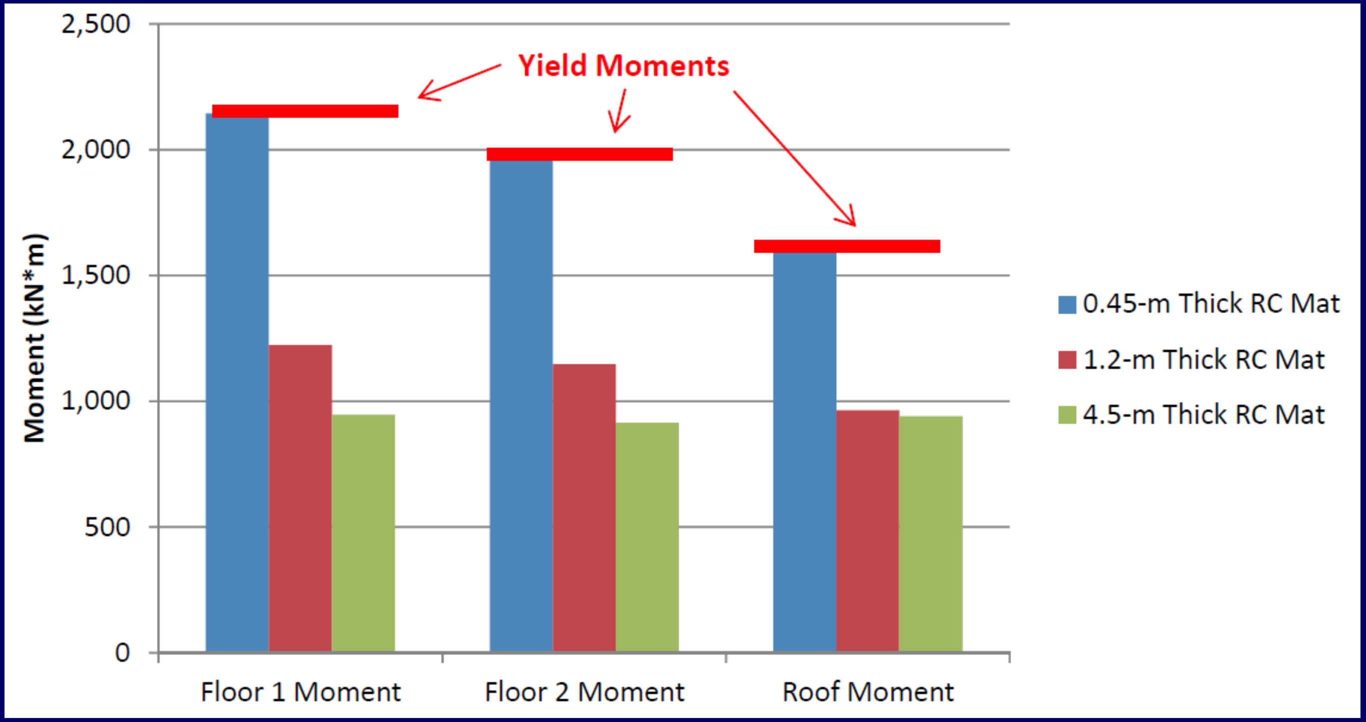
Fault-Structure Interaction Analyses



15 m deep sand deposit

70 cm reverse fault displ.

(Oettle & Bray 2013)

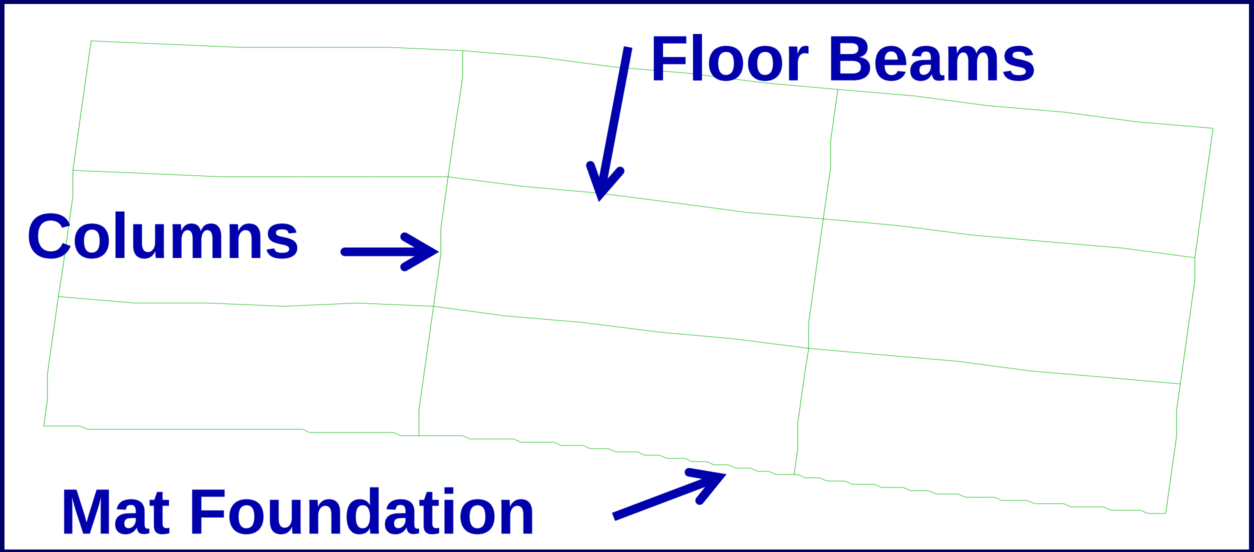


Thicker mat foundation significantly reduces building damage

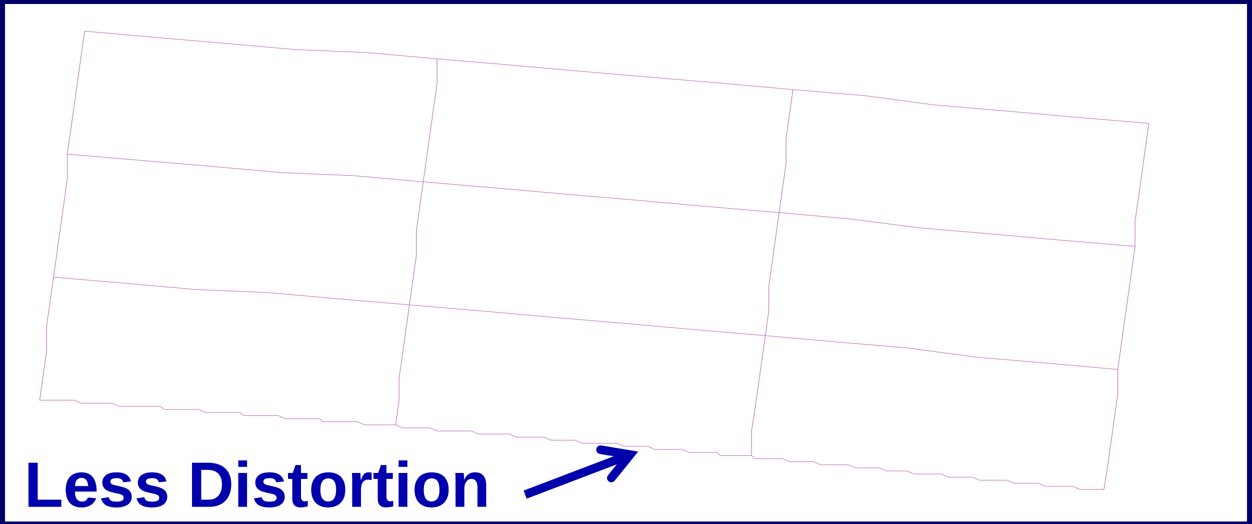
Mitigation with Thick Mat Foundation

Thicker mat foundation "shields" structure from ground deformation

Mat Thickness
= 0.45 m

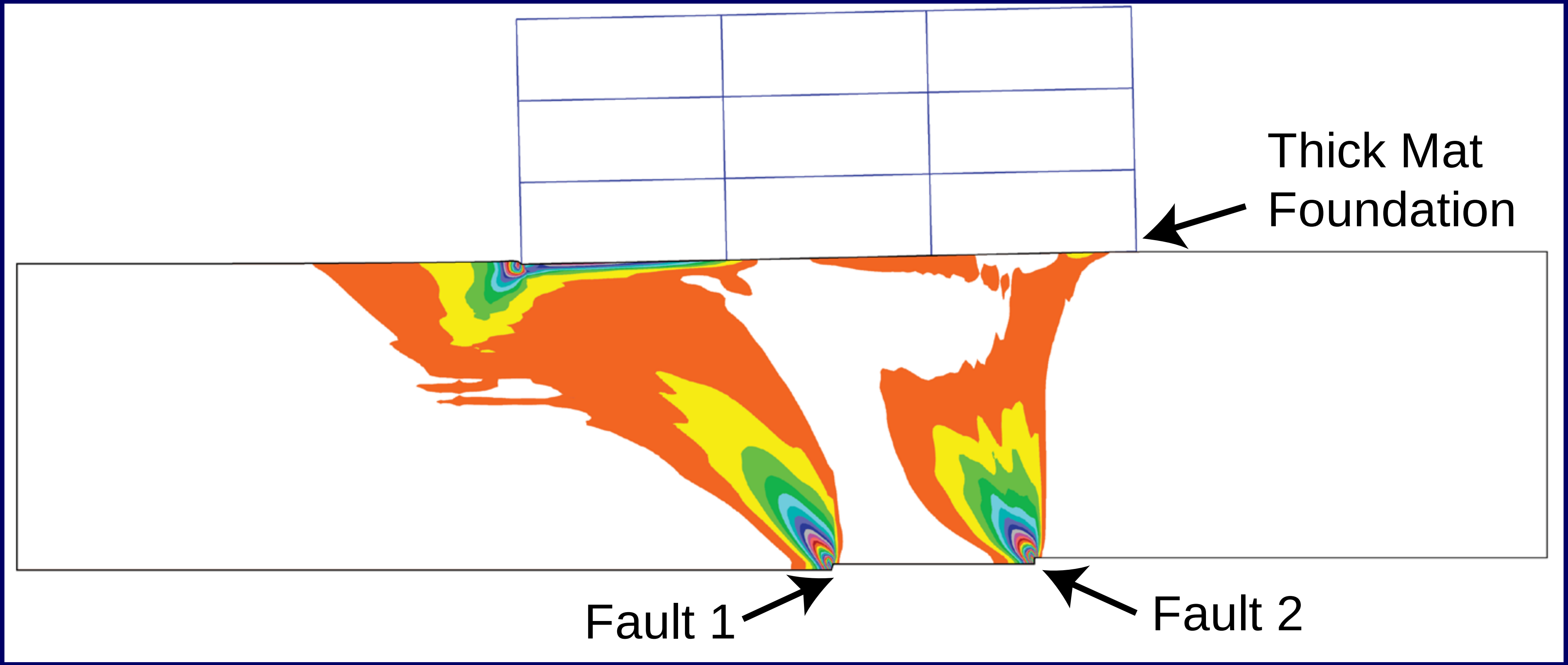


Mat Thickness
= 1.2 m



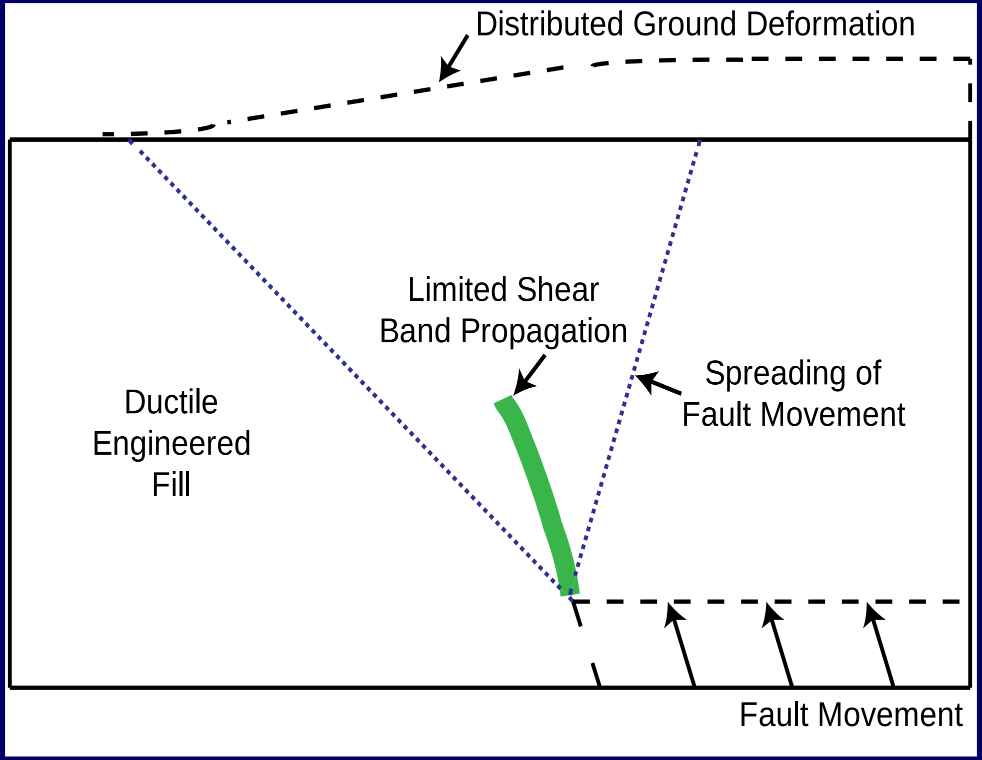
Oettle and Bray (2013)

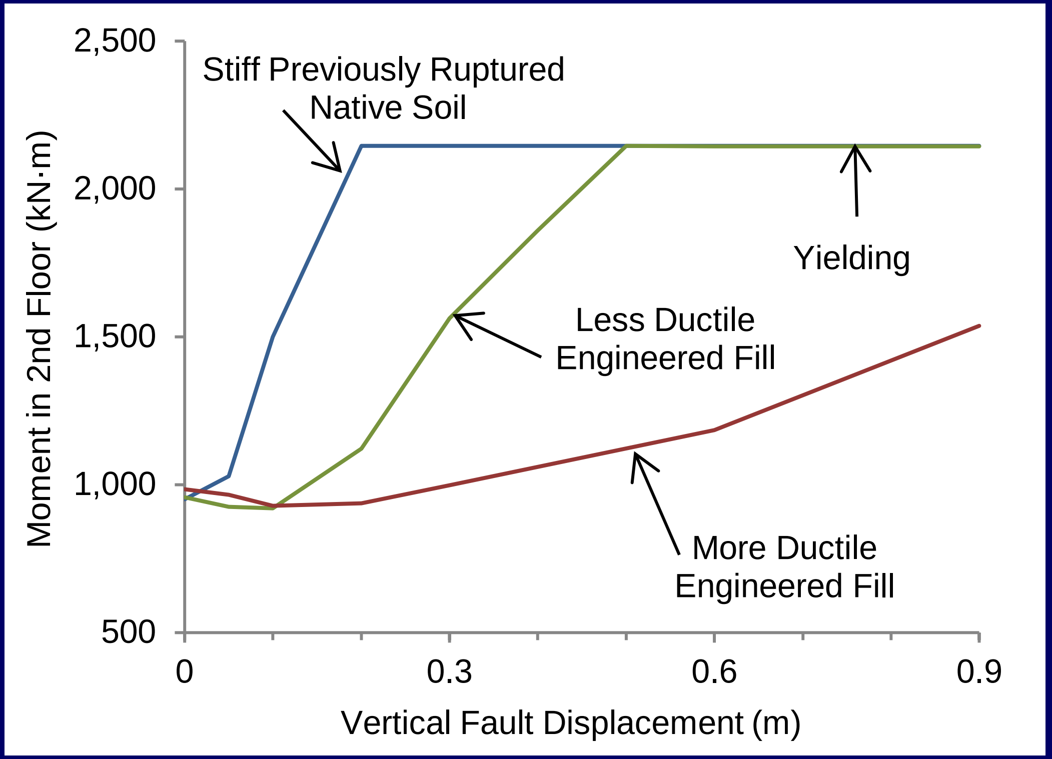
Mat Foundation
(Induces Rigid Body Building Movement)



Oettle and Bray (2013)

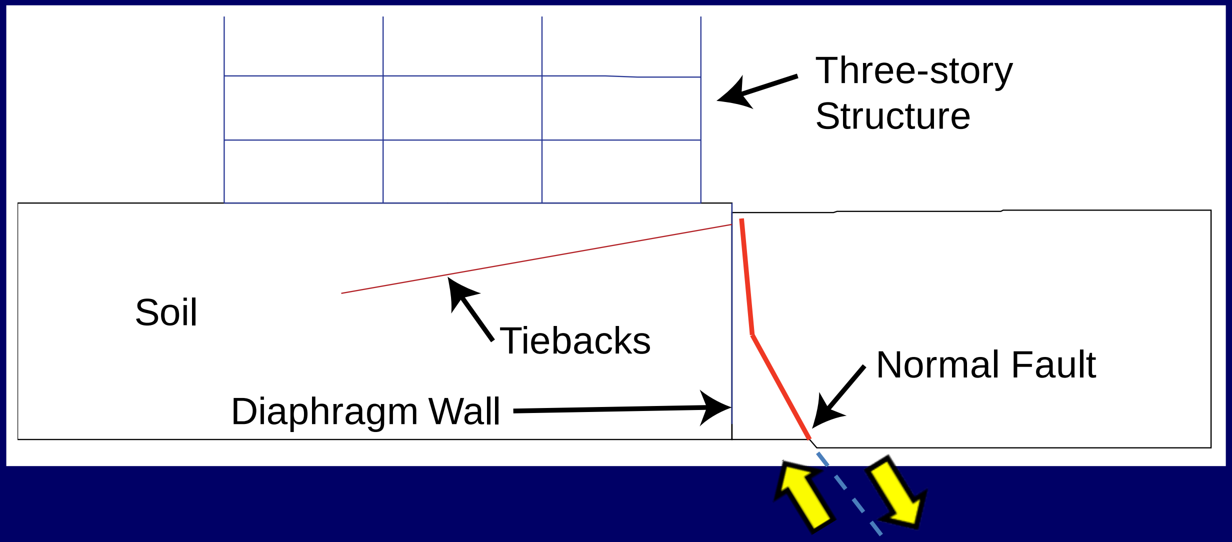
Engineered Fill (Diffuse Underlying Fault Movement)

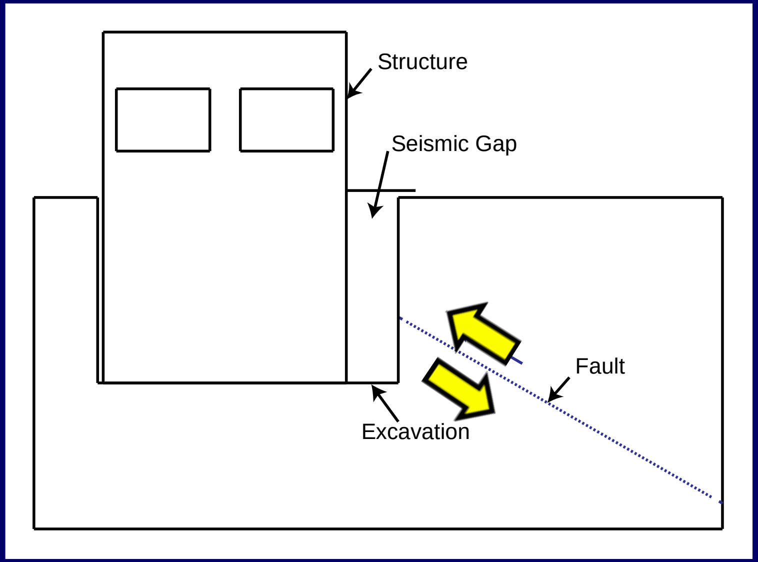




Oettle and Bray (2013)

Fault Diversion
(Shield / Protect Structure)





Oettle and Bray (2013)

SURFACE FAULT RUPTURE ENGININEERING DESIGN

ENGINEEERING GEOLOGIST

- Identify and characterize faults
- Estimate amount of potential fault displacement

GEOTECHNICAL ENGINEER

- Construct ductile reinforced soil fills to spread out movement
- Use slip layer to isolate ground movements from foundation
- Place compressible materials adjacent to walls and utilities

STRUCTURAL ENGINEER

- Design strong, ductile foundations, with flexibility
- Avoid the use of piles
- Professionally responsible for life-safety of building occupants