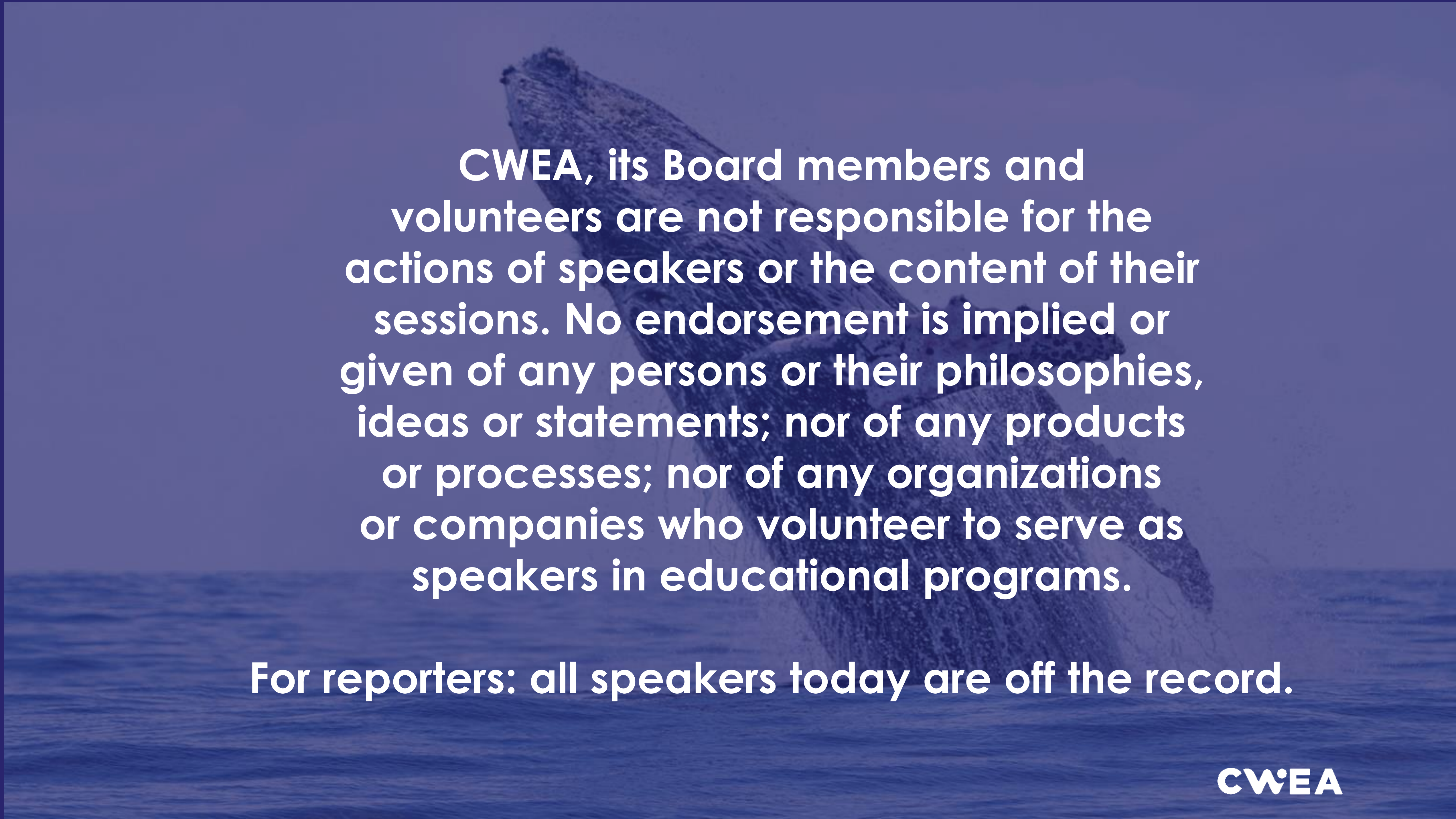
SANTA ANA RIVER BASIN SECTION

Seismic Considerations for Water Infrastructure: Displacement Hazard Analysis and Soil Liquefaction

CWEA

CWEA WEBINAR, October 18, 2022



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TBD

Achieving Class A Biosolids With Temperature Phased Anaerobic Digester Facility

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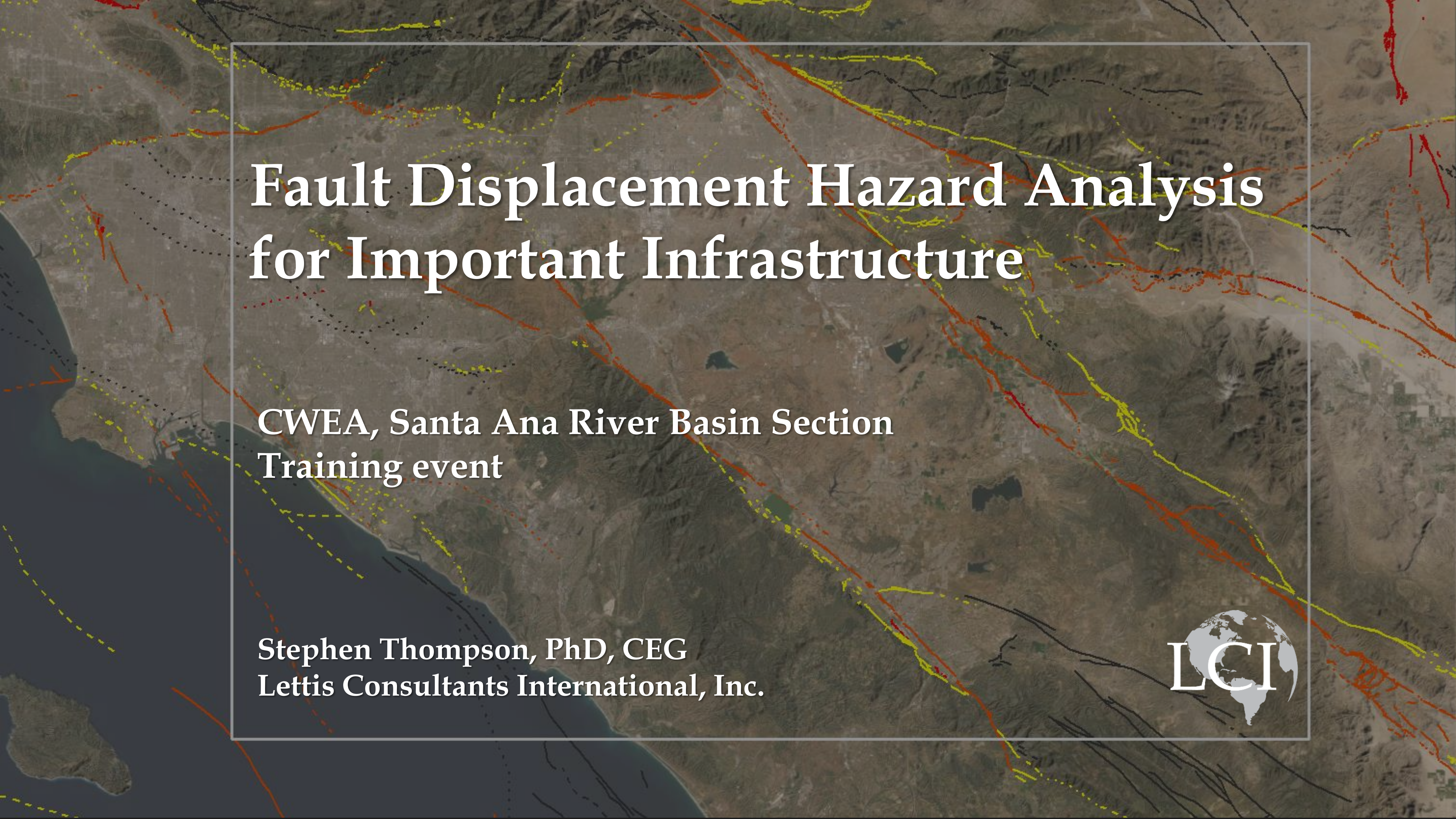
Topic: Fault Displacement Hazard Analysis

Stephen Thompson, PhD, CEG

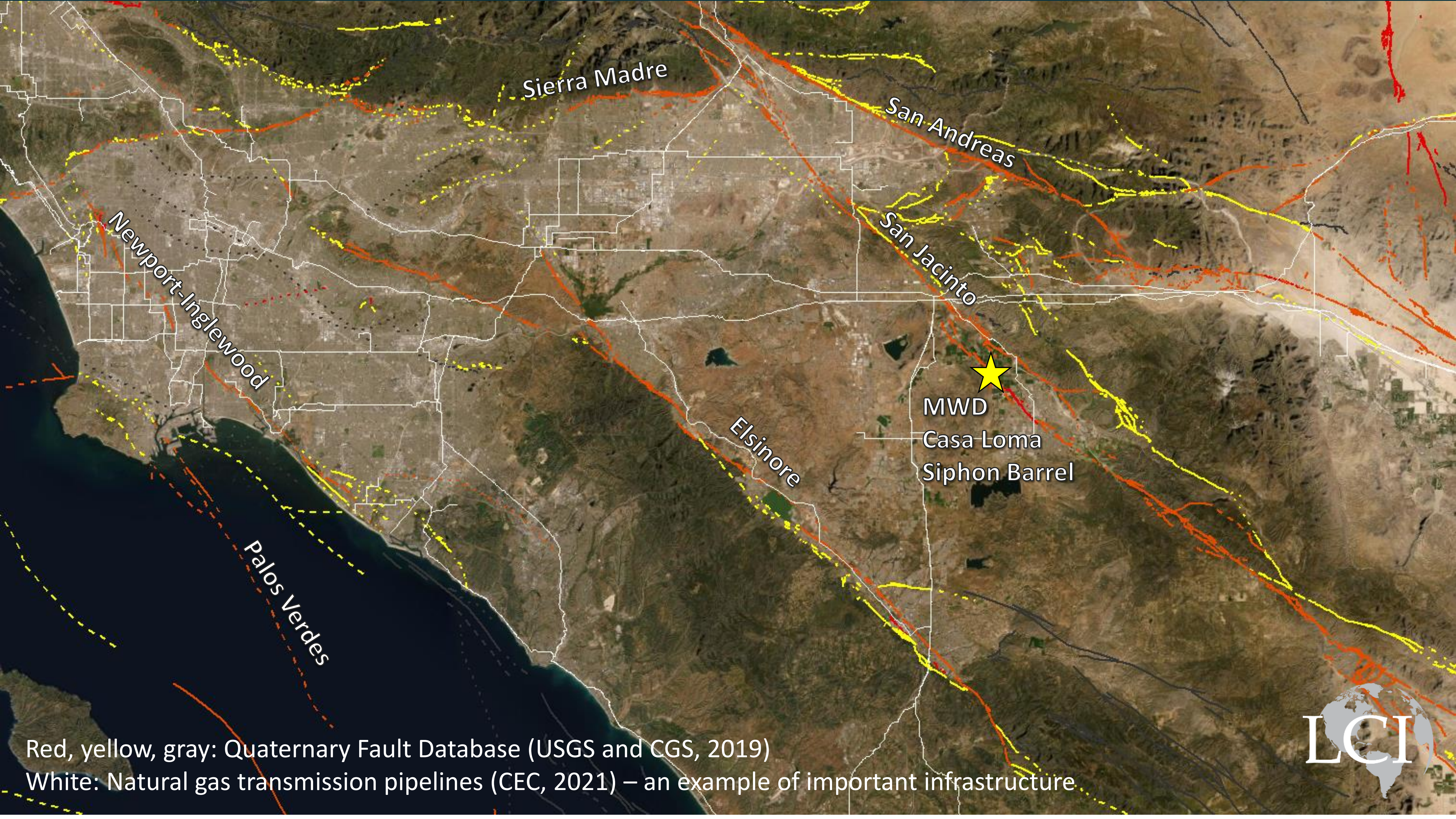
Principal Geologist
Lettis Consultants International, Inc.



Fault Displacement Hazard Analysis for Important Infrastructure

CWEA, Santa Ana River Basin Section
Training event

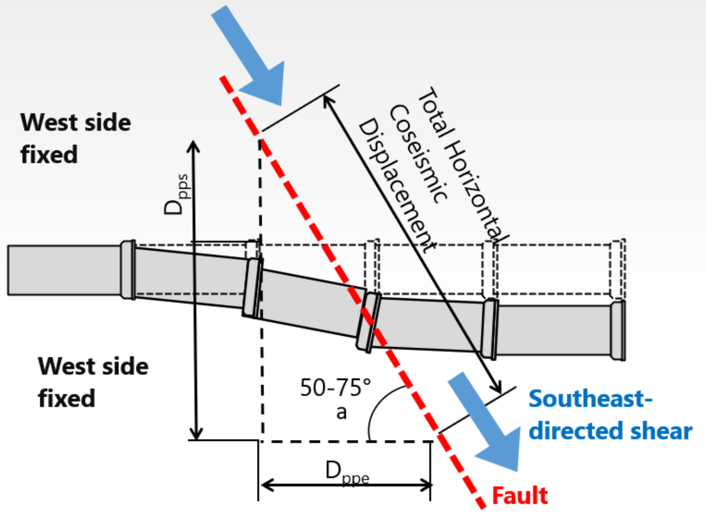
Stephen Thompson, PhD, CEG
Lettis Consultants International, Inc.



Red, yellow, gray: Quaternary Fault Database (USGS and CGS, 2019)
White: Natural gas transmission pipelines (CEC, 2021) – an example of important infrastructure

Talk Outline

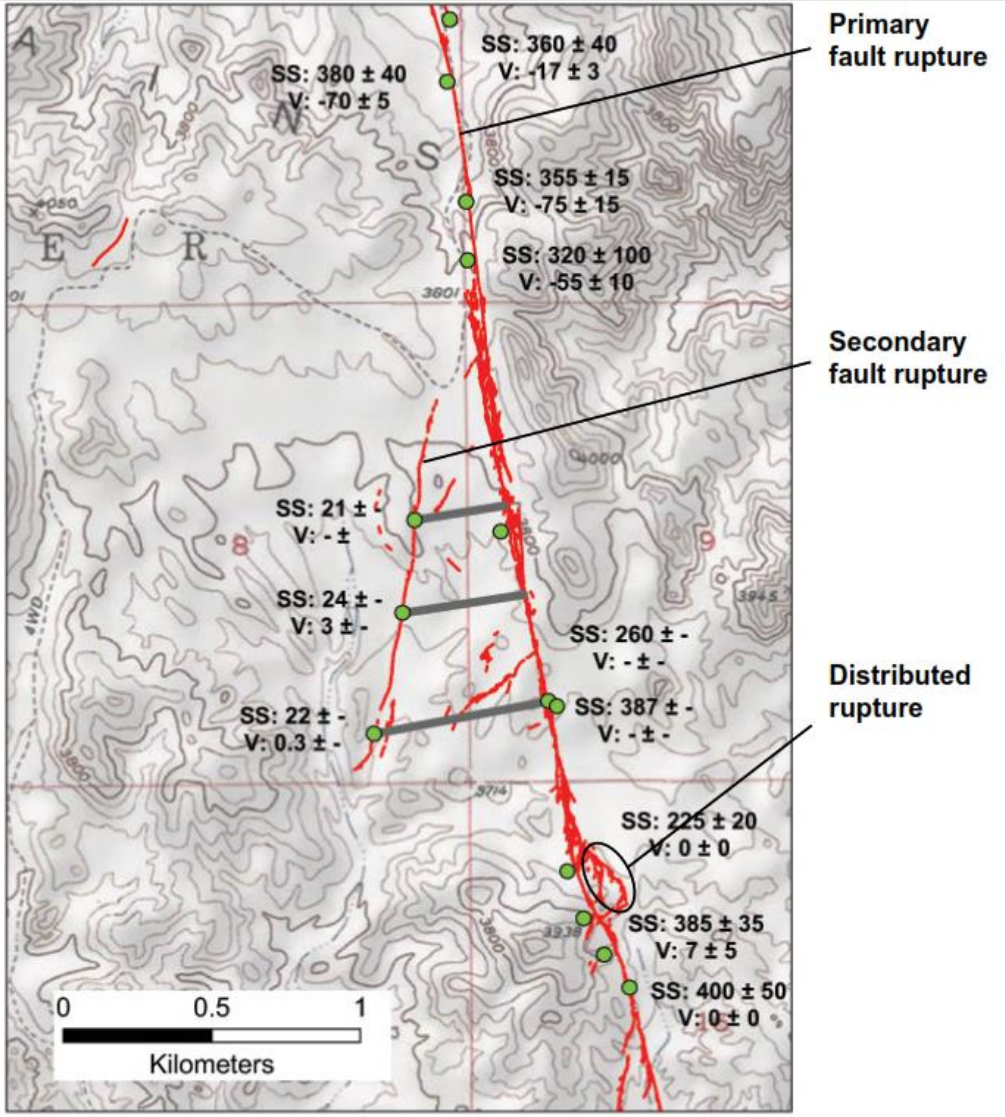
- Current practice in fault displacement hazard analysis
  - Site exploration
  - Hazard zone mapping
  - PFDHA / DFDHA
- Interpreting hazard results for engineering decision-making

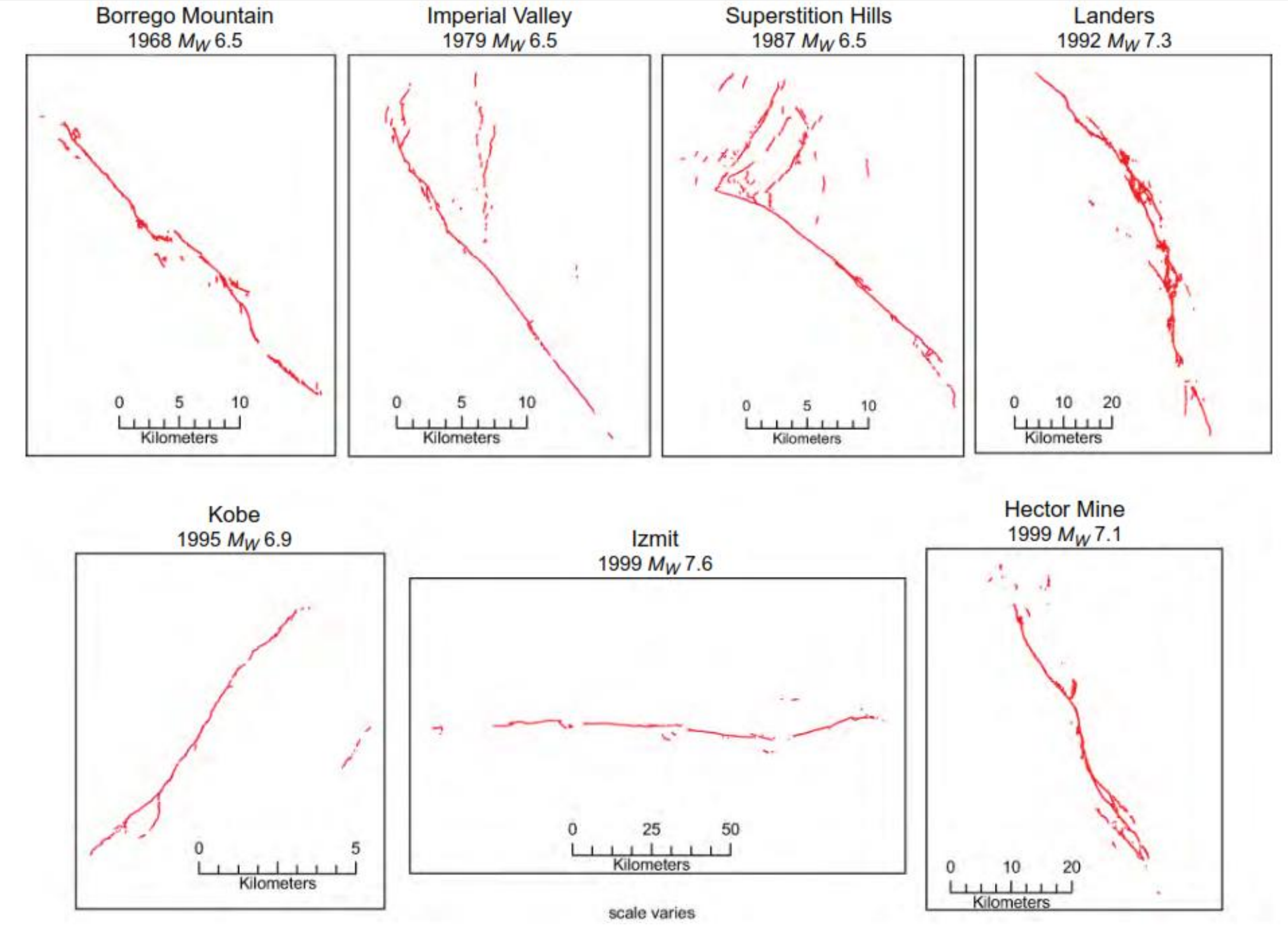


Acknowledgements:

- Robert Givler, Ross Hartleb, Scott Lindvall, Arash Zandieh (LCI)
- Darren Baune (Carollo Engineers)

Examples and Types of Surface-Fault Rupture





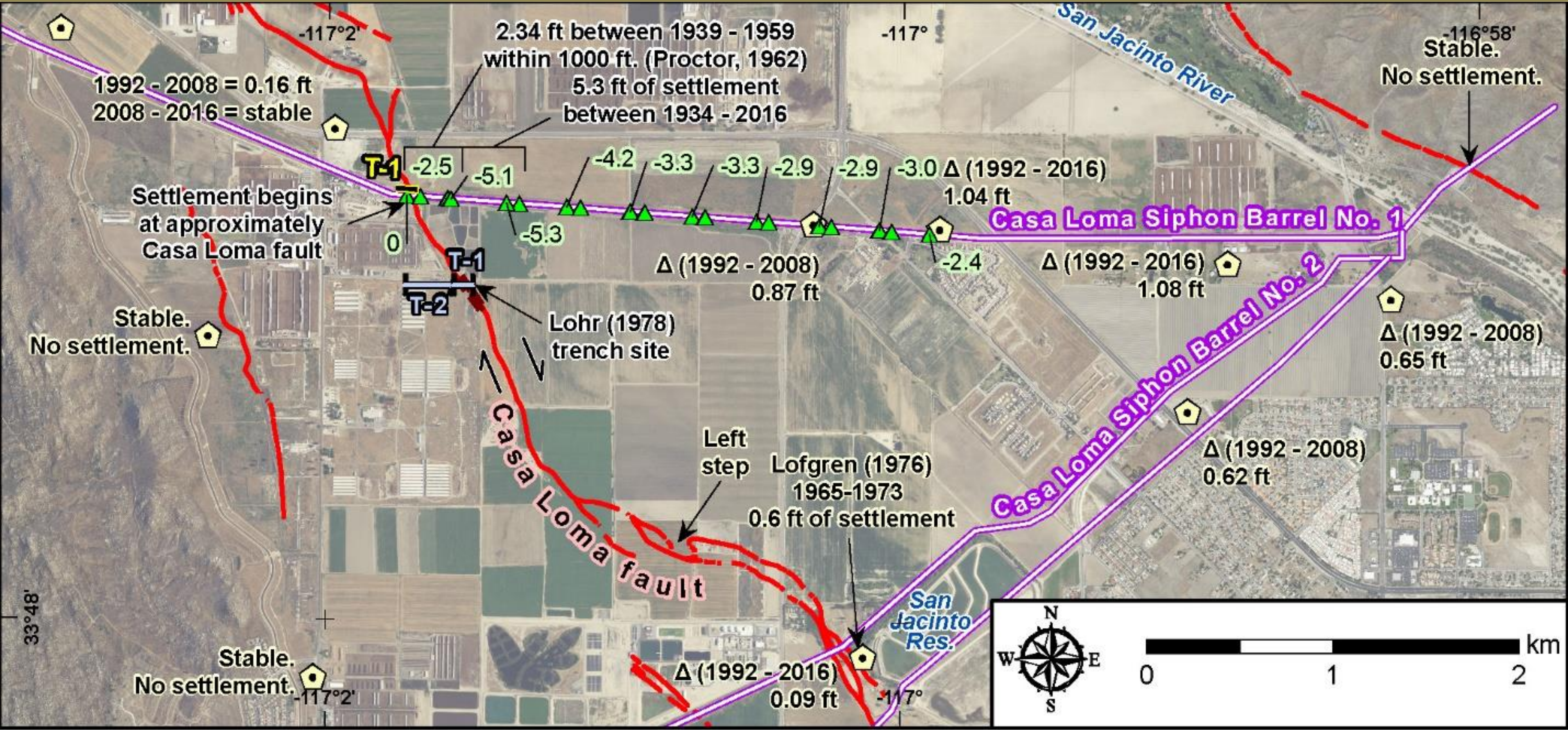
From Petersen et al. (2011)

Site Characterization

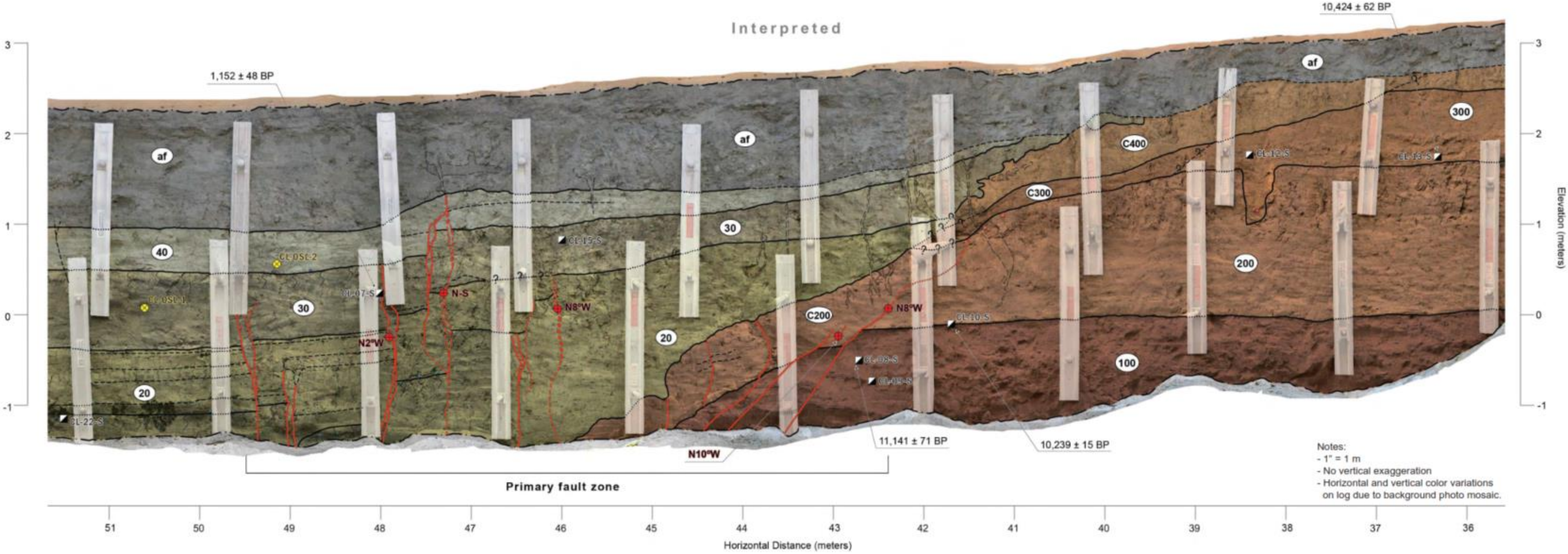
- Data Compilation
- Geologic Mapping
- Subsurface Exploration
  - Trenching
  - Drilling
  - CPT
  - Geophysics

Preferred method(s) will depend on the site conditions and goals of the project

Site Characterization – MWD Casa Loma Example



Site Characterization – MWD Casa Loma Example



Notes:
- 1" = 1 m
- No vertical exaggeration
- Horizontal and vertical color variations on log due to background photo mosaic.

Exploratory trench used to refine the location and width of the fault zone

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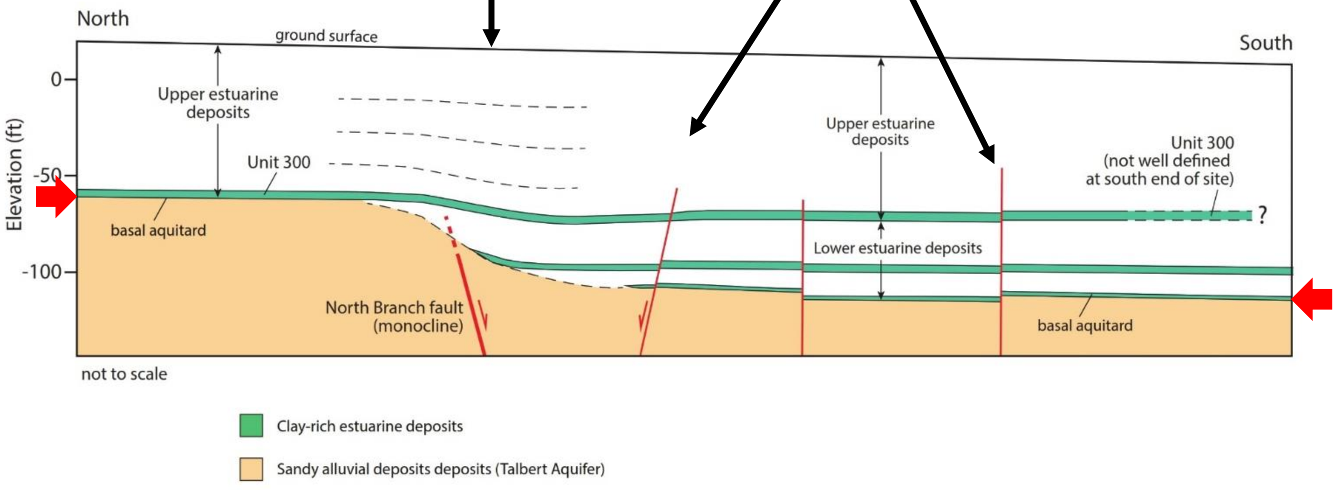
Site Characterization example

Site size and stratigraphy conducive to CPT transects

Fold-related ground deformation

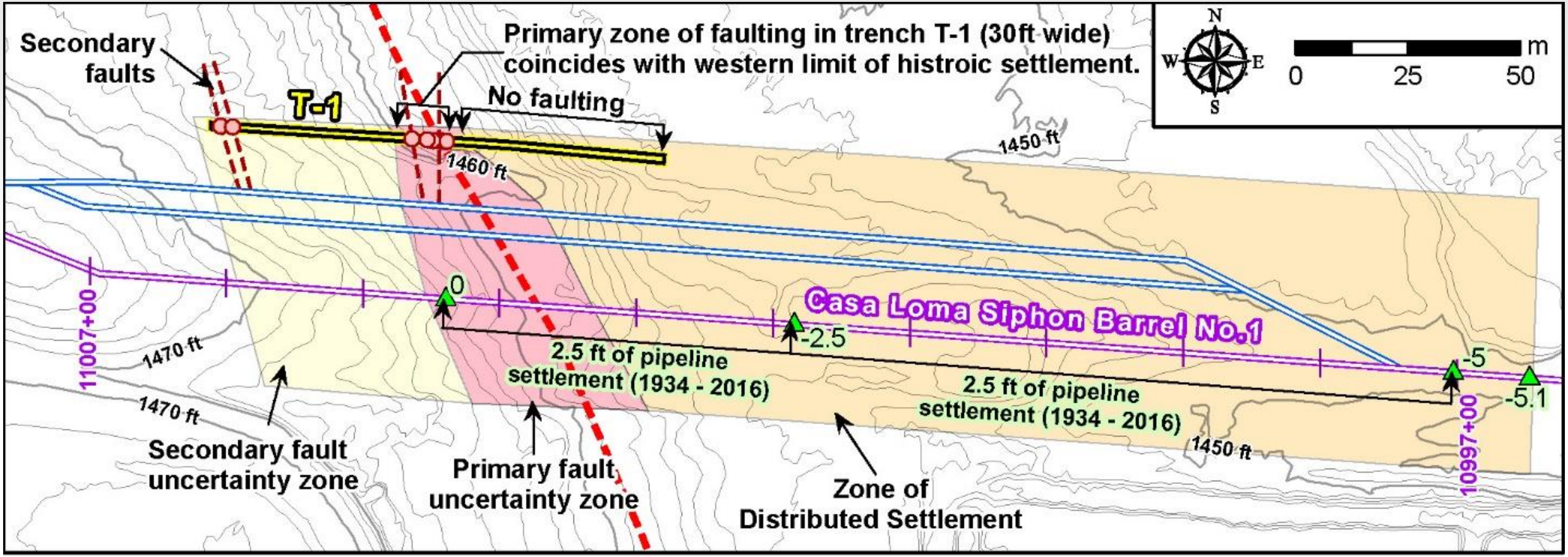
Brittle faulting between CPTs spaced ~20-40 ft



Hazard Zone Mapping

- Show areas of higher and lower hazard
- Zones should convey *uncertainty* in fault location and *limitations* of site characterization
- Can be used for mitigation by avoidance

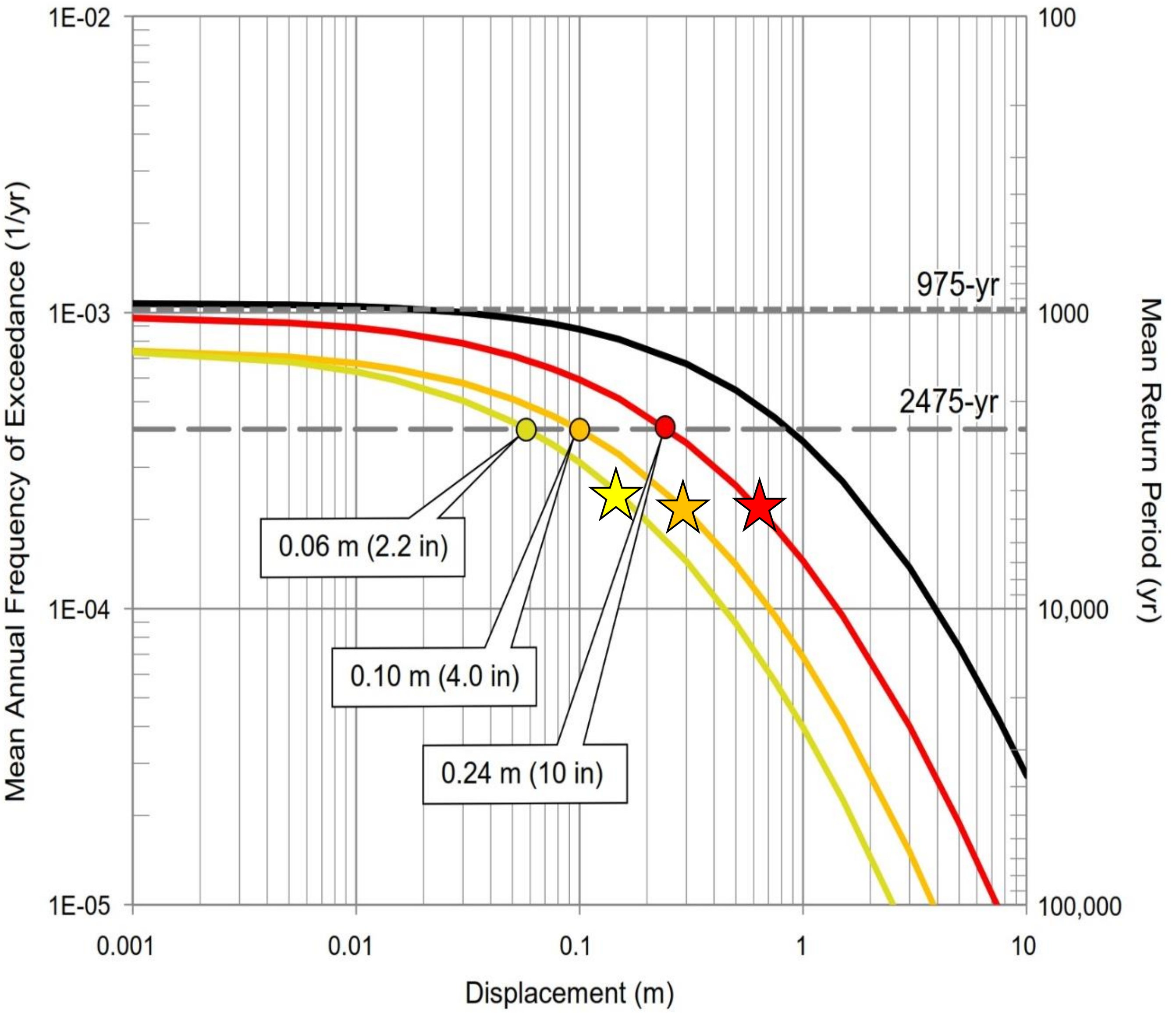
Hazard Zone Mapping – MWD Casa Loma Example



Red dots represent faults in trench T-1 and maroon dashed lines show orientation of faults in the trench. Green triangles are settlement estimates from Metropolitan (2016). Grey lines represent 1-ft topographic contours. Blue lines are proposed retrofit pipelines.

Displacement Hazard Analysis (PFDHA and DFDHA)

- For mitigation by design or post-event response plan
- Probabilistic approach similar to PSHA in ground motions
- Deterministic approach useful for understanding simple scenarios
- Provide AMOUNT of displacement



Deterministic estimates

LEGEND

▬ Principal faulting

Secondary Faulting

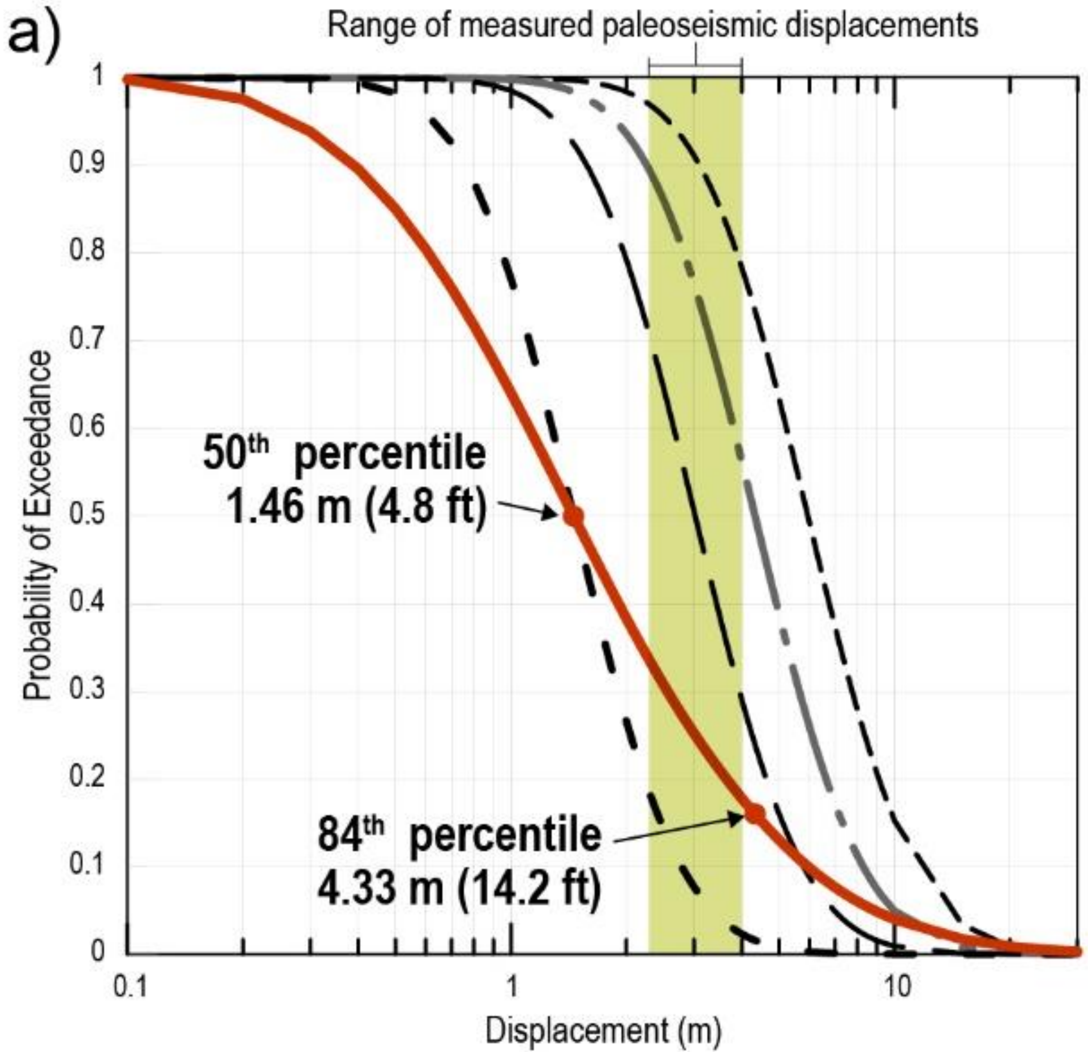
★ ▬ North Branch monocline

★ ▬ Larger secondary faults

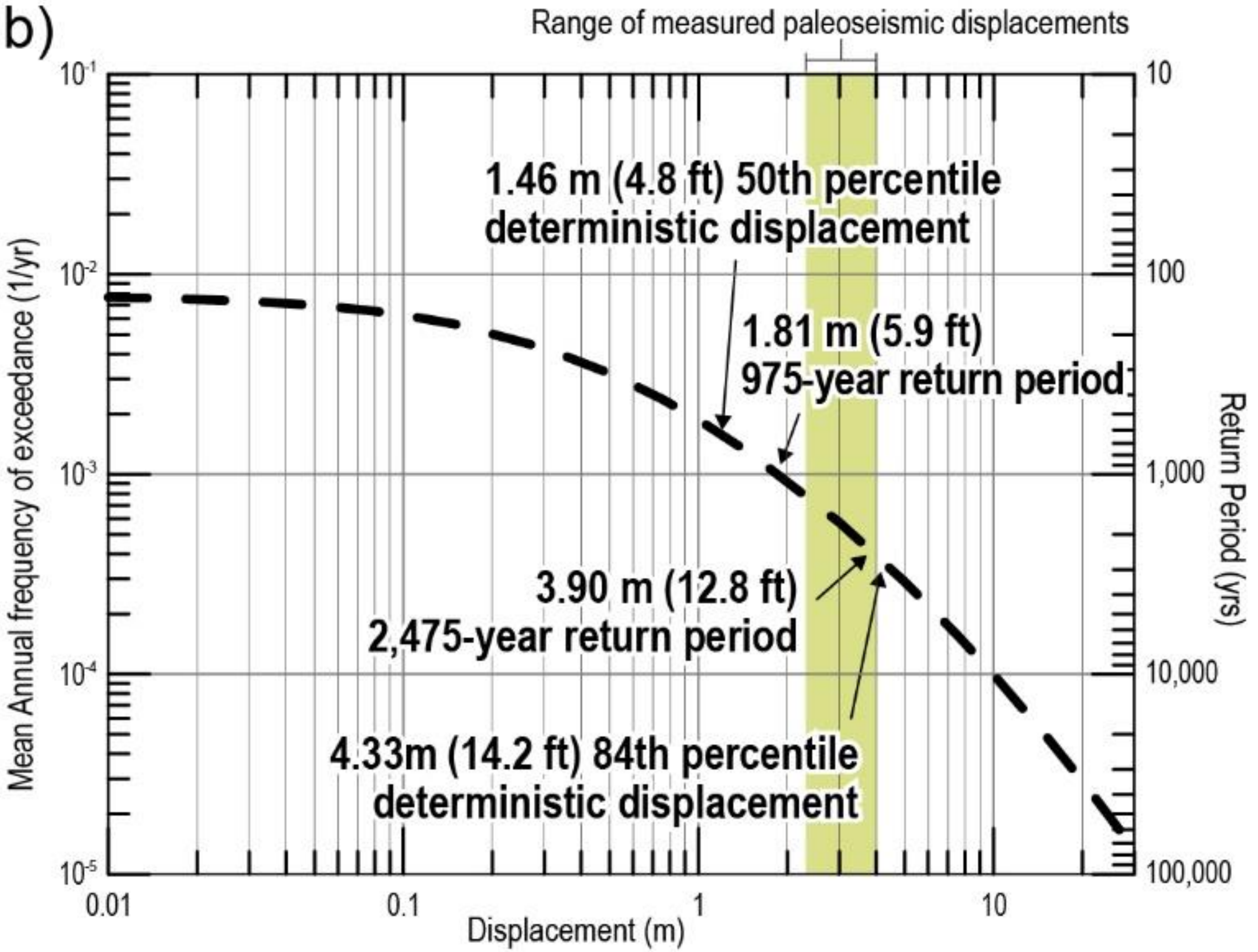
★ ▬ Smaller secondary faults

Displacement Hazard Analysis – Casa Loma Example (Principal Fault Hazard at Crossing)

Deterministic Results



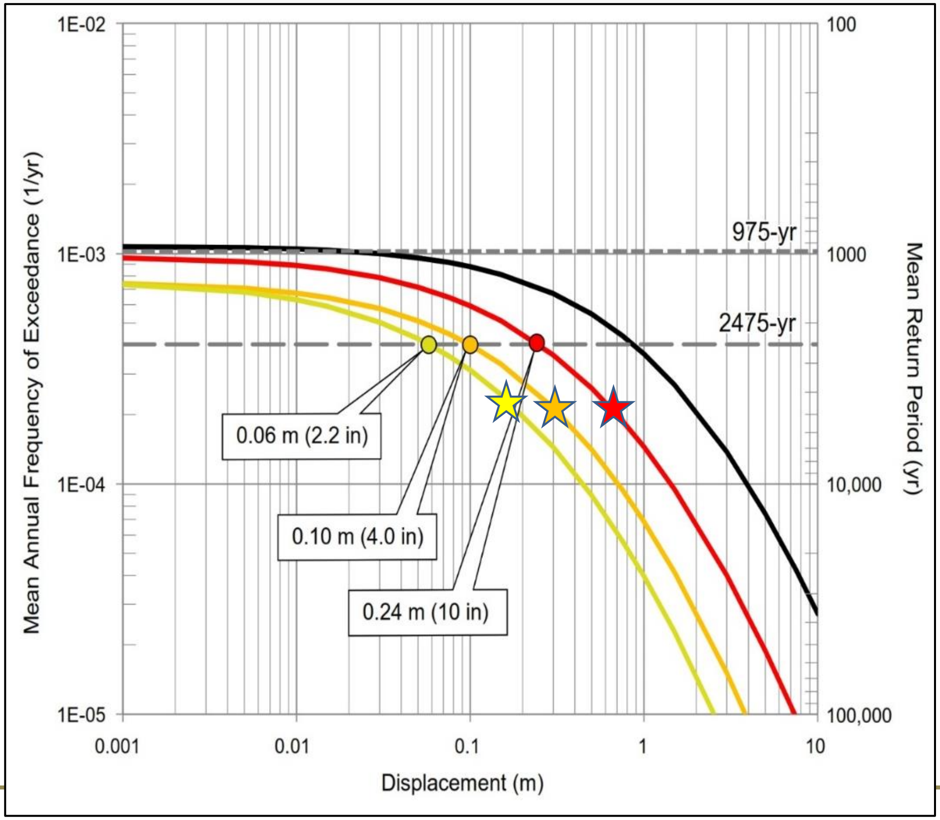
Probabilistic Results



Interpreting Hazard Results and Mitigation Strategies

- Regulations and Guidance
  - Alquist-Priolo Act (human-occupied structures)
  - DSOD (dams)
  - ALA guidelines
  - Agency design criteria (LADWP, MWD, SFPUC)
- Mitigation options:
  - Avoidance
  - Design
  - Post-event response

- Considerations:
  - Deterministic (scenario) values vs probabilistic results at a target return periods
  - Incremental costs or threshold costs for mitigating higher displacement amounts?



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Topic: Soil Liquefaction and Liquefaction Mitigation

Sergio Duarte, PE

Project Engineer – Geotechnical
AECOM

SANTA ANA RIVER BASIN SECTION

CWEA

Soil Liquefaction and Liquefaction Mitigation Methods

CWEA WEBINAR, October 18, 2022

What is soil liquefaction?

As the name implies, it is the soil liquid-like behavior during a seismic event

“Liquefaction takes place when loosely packed, water-logged sediments at or near the ground surface lose their strength in response to ground shaking”
U.S. Geological Survey (USGS)

“Earthquake motion can turn loosely packed, water-saturated soil to liquid—"liquefaction.” Liquefied soil loses its density and ultimately the ability to support roads, buried pipes, and, of course, houses”
California Earthquake Authority

“ground failure or loss of strength that causes otherwise solid soil to behave temporarily as a viscous liquid” Britannica.com

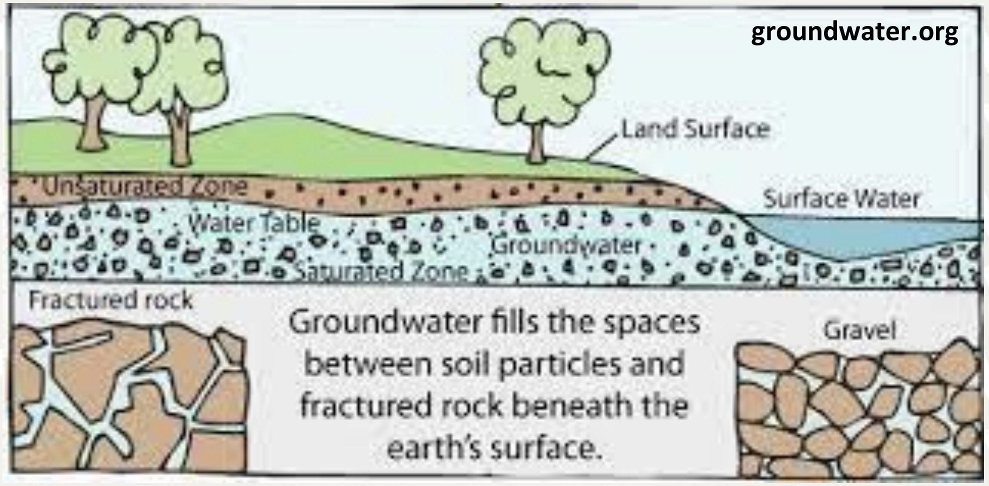
Soil liquefaction can cause damage to structures, including but not limited to buildings, bridges, dams, and pipelines. Understanding the conditions required for liquefaction, potential consequences, and ways to mitigate should be considered in the design of any structure.

The presentation will introduce this seismic hazard and provide the attendees typical consequences of liquefaction. The presentation will also present some common ground improvement methods available to mitigate this hazard.

Components needed for soil liquefaction to occur

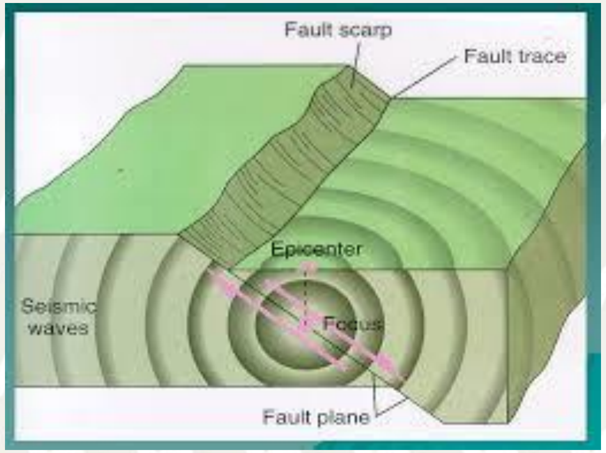
Annystudio.com

Loose, granular soils. Such as sands and some silts


groundwater.org

Groundwater fills the spaces between soil particles and fractured rock beneath the earth's surface.

Water; typically, shallow groundwater



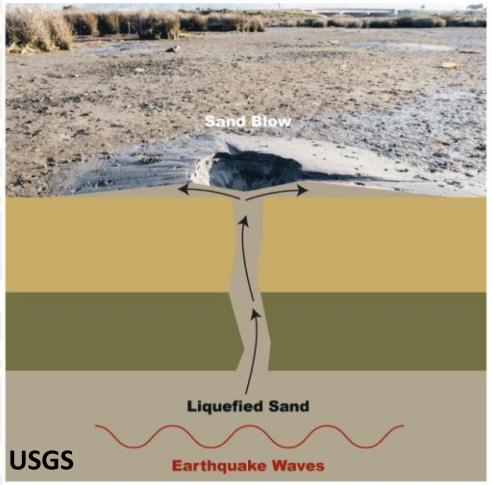
Instantaneous loading (Seismic Event)

What causes liquefaction

During a seismic event, the sudden shaking increases the pore water pressure within the saturated soils to a point that the soil particles can readily move with respect to each other (liquefaction)

When liquefaction occurs, the strength of the soil decreases and the ability of the soil to support foundations.

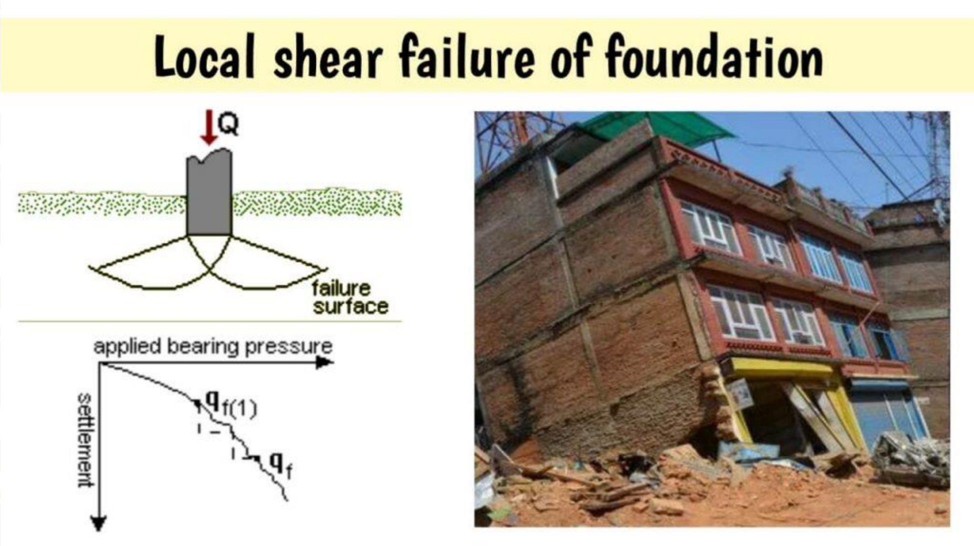

California Earthquake Authority



USGS

Sand boils (sand blows) can also occur during a seismic event. Sand boils can remove bearing soil beneath buildings, causing voids, and ultimately excessive (localized) settlement

Consequence of soil strength loss, relative to a building, can be:



- Reduction of bearing capacity
- Total and differential settlement, and
- Horizontal ground displacement

Soil Liquefaction has caused tremendous amounts of damage in historical earthquakes around the world

Houses damaged by the 1906 San Francisco Earthquake

M 7.9

Photo credit:
U.S. Geological Survey Photographic Library
(http://libraryphoto.cr.usgs.gov/index.html)

Liquefaction of sediments in Mexico City caused the collapse of many buildings in the 1985 earthquake.

M 8.0

Rotation and settlement of building due to liquefaction, Turkey, 2001

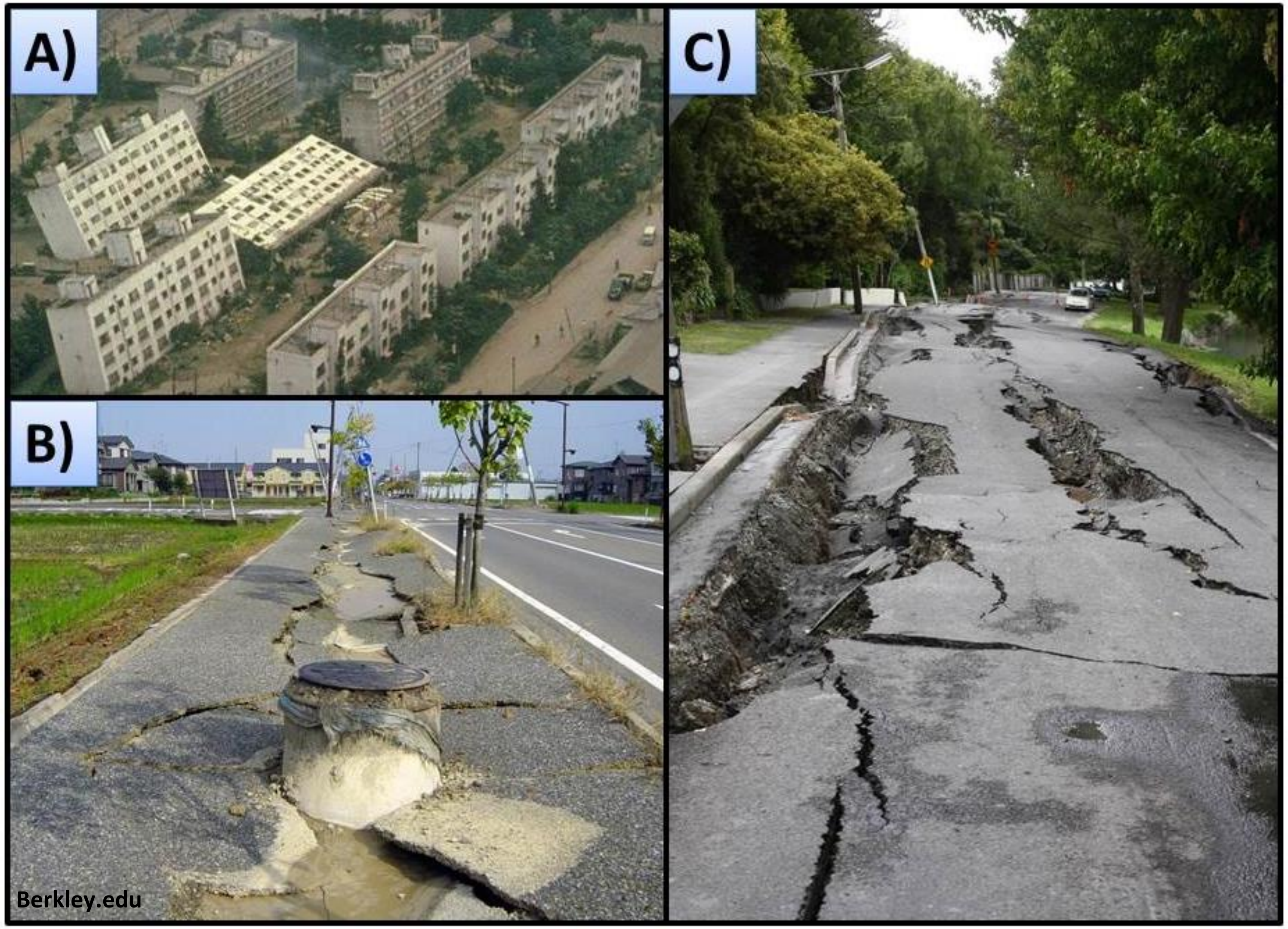
M 7.4

Soil Liquefaction has caused tremendous amounts of damage in historical earthquakes around the world

A. Tilted apartment buildings due to liquefaction
1964 Niigata Japan earthquake
(probably the most well-known example of liquefaction and loss of bearing strength)

B. Damage to road and sidewalk
2004 Chuetsu, Japan earthquake

C. Damage to roadway
2011 Christchurch, New Zealand earthquake

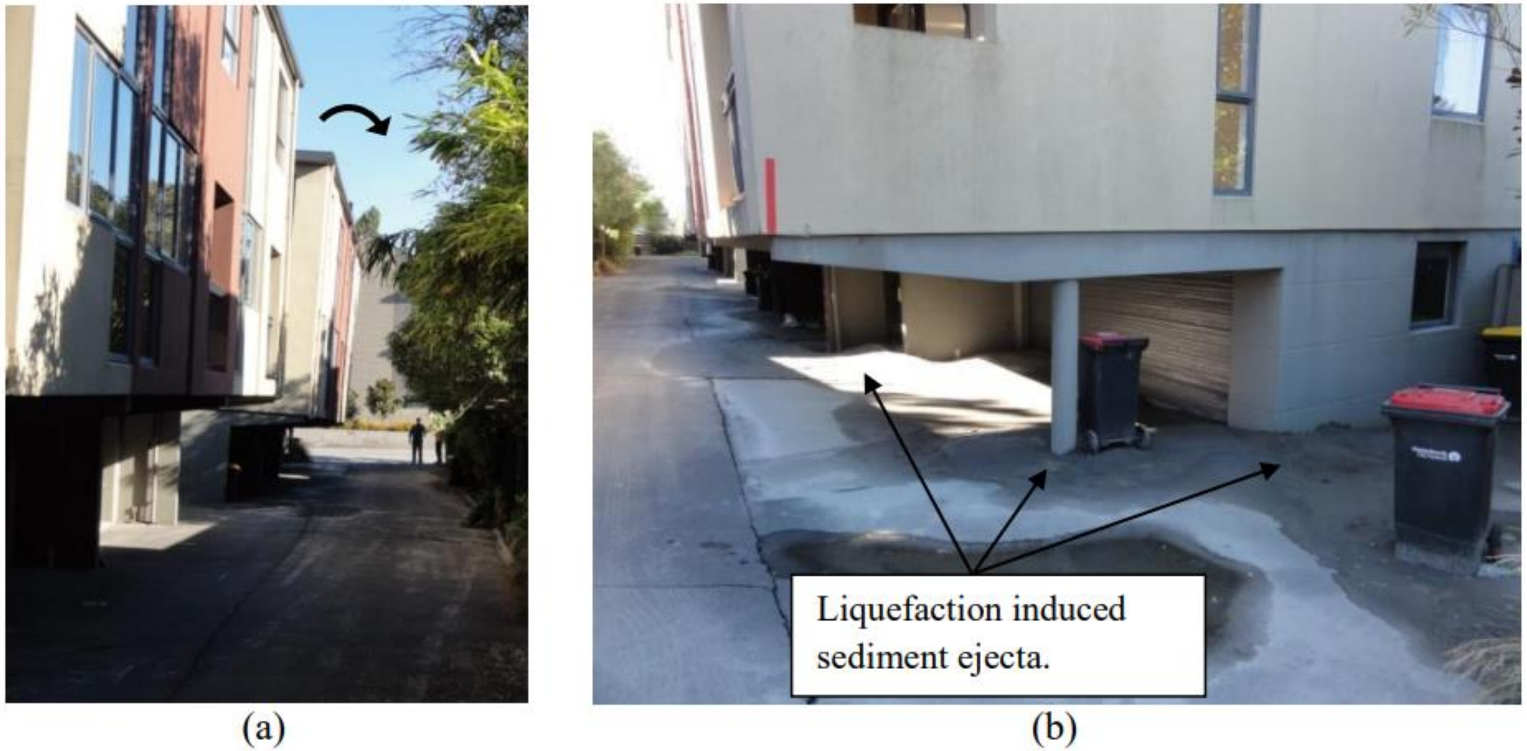


Berkley.edu

Soil Liquefaction has caused tremendous amounts of damage in historical earthquakes around the world

2011 Christchurch, New Zealand EQ

Building tilting



(a) (b)

Figure 4-12. Apartment complex: (a) looking south from northern building showing tilt of southern building, and (b) looking north at liquefaction feature at edge of southern building (7 Mar 2011; -43.52434°, 172.64432°).

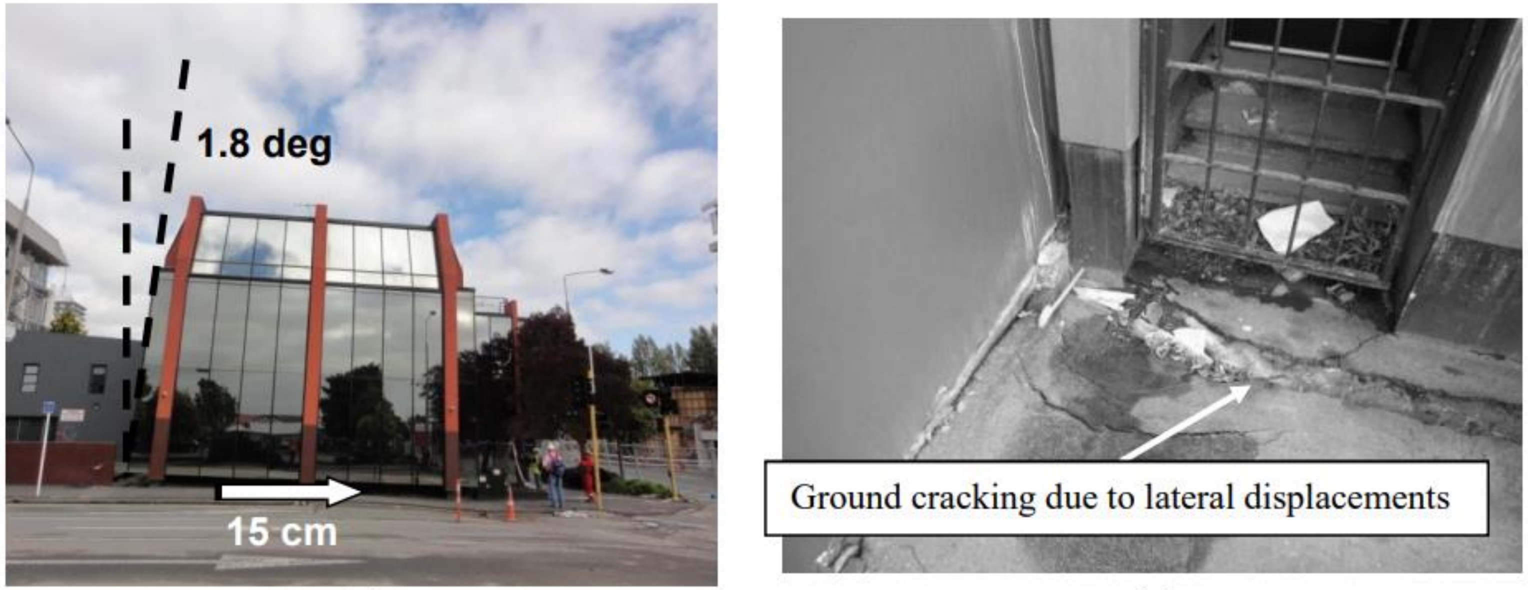
M 6.3
Northridge: M 6.7

GEOTECHNICAL RECONNAISSANCE OF THE
2011 CHRISTCHURCH, NEW ZEALAND EARTHQUAKE

Soil Liquefaction has caused tremendous amounts of damage in historical earthquakes around the world

2011 Christchurch, New Zealand EQ

Differential settlement and sliding of building



(a) (b)

Figure 4-17. Liquefaction-induced differential settlement and sliding of building in the CBD (24 Mar 2011; -43.52878°, 172.64252°).

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How to evaluate liquefaction risk

Site Investigation

- Typically, Borings and/or CPTs
- Borings should be extended to at least 50 feet for liquefaction analysis
- Sample collection for laboratory testing is critical

Desktop Data Research

- Seismic Hazard Maps
- Depth to groundwater, both recent and historic
- Seismic Design Parameters based on structure type and jurisdiction

How to evaluate liquefaction risk

Risk Evaluation Based on Desktop and Field Data

- Are potentially liquefiable soils present?
- If present, are they saturated or may become saturated in the future?
- What is the maximum depth of potentially liquefiable soils?
- What would be the extend of liquefaction damage?

Liquefaction potential is evaluated using correlations and analyses based on in-situ standard penetration tests (SPTs) blowcounts and correlations and analyses based on in-situ Cone Penetration Test (CPT) data

Answers to this questions help the designer determine the type of mitigation to recommend

Mitigation Assessment

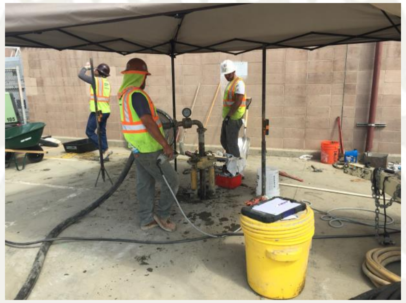
Considerations

- Size of project
- Site constraints (geometry, resources, noise and dust restrictions, etc.)
- Groundwater table
- Soils Types (gradations, plasticity)
- Depth of liquefiable soils
- Expected settlement (total and differential)
- Structure design (tolerable settlements)
- Cost

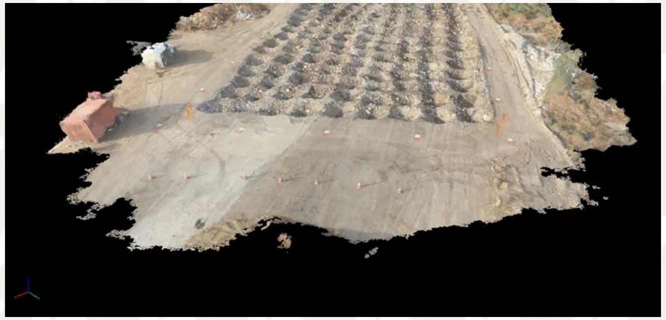
Typical ground improvement methods to mitigate soil liquefaction

Remedial Grading

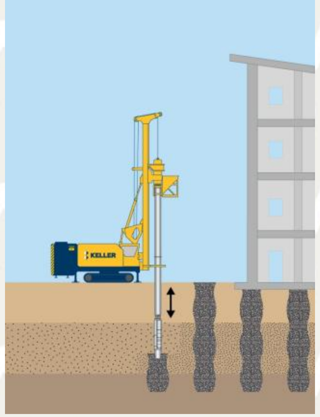
Deep Foundations



Grouting



Dynamic Compaction



Vibro Stone Columns

Mat Foundations

Remedial Grading (Remove and Replace)

Used to densify loose soils by removing and replacing the existing soils with compacted soils

Pros:
-Relatively fast compared to other methods
-Good for liquefiable soils within 20 feet of ground surface
-Limitations due to project size

Cons:
-Costly due to amount of soil needing to be removed
-No good for deeper liquefiable soils
-Difficult with shallow groundwater

Quality assurance controlled by geotechnical testing (compaction, Gradations, Atterberg limits)

Deep Foundation Foundations

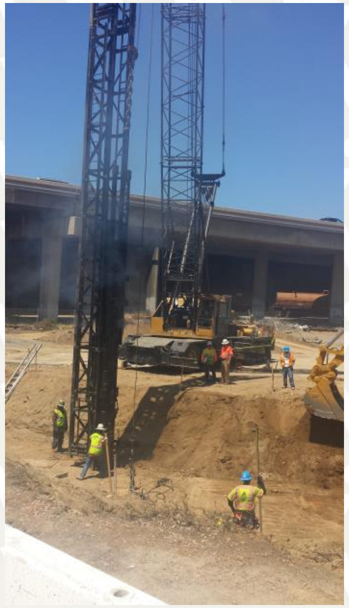
Piles can be:

- Driven, or
- Drilled-in-place

- Selection depends on site demands and constraints (shear, moment, groundwater, soil type)

- Piles are typically driven/drilled to very dense soil layer or bedrock

- Need to consider liquefaction down drag forces



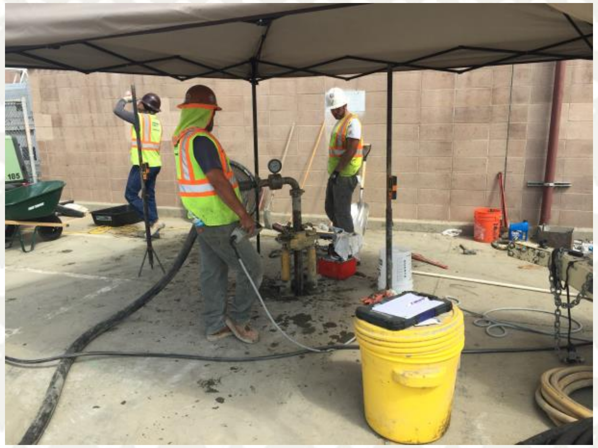
Deep Foundation Foundations

Cast-In-Drilled-Hole (CIDH) Piles

Drilled piers (36” Dia.)

Quality assurance of pile integrity is typically done with crosshole sonic logging (CSL) and/or Gamma-Gamma logging through pipes placed within the reinforcement. Load testing typically done to verify load capacity

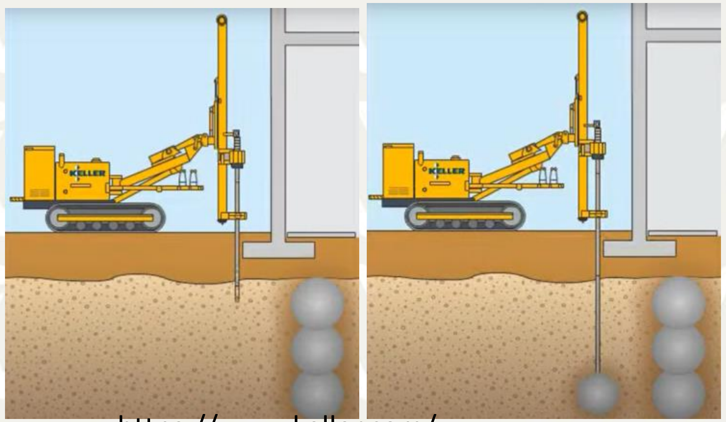
Compaction Grouting



Injection of grout to densify loose, granular soils

Pros:
- Can be done on existing structures
- Typically, more economic over removal and replacement, or piling.
- Good for difficult access areas.

Cons:
Success depends on quantity of fines in subsurface soil

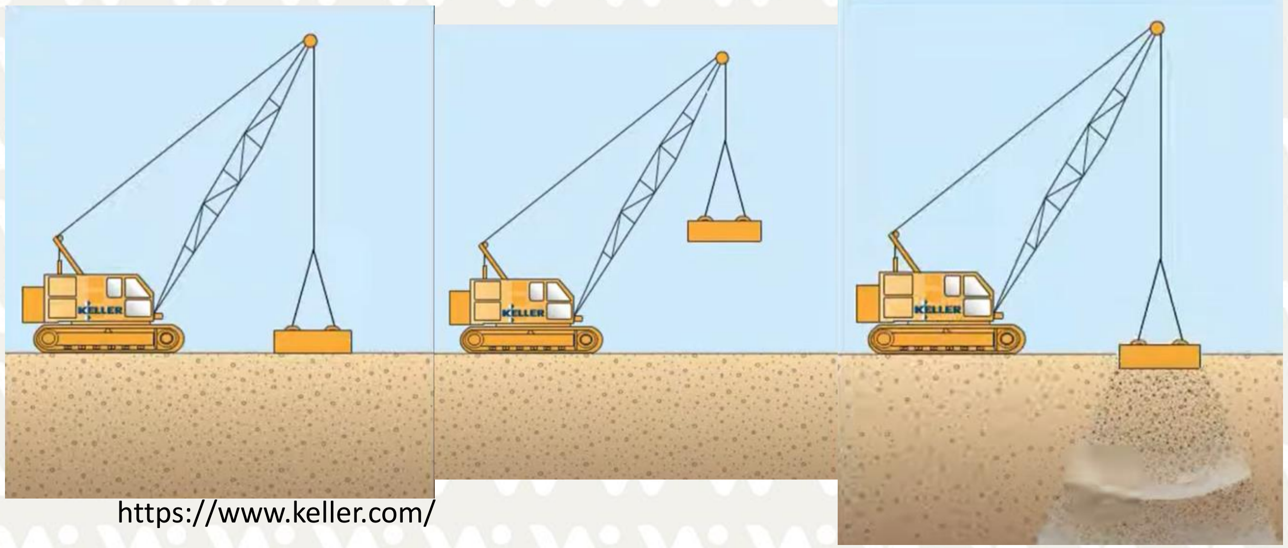


https://www.keller.com/

Quality assurance is typically done with CPTs, in conjunction with volume of grout calculations

Dynamic Compaction

In addition to mitigating liquefaction, dynamic compaction increases bearing capacity and decreases static settlement



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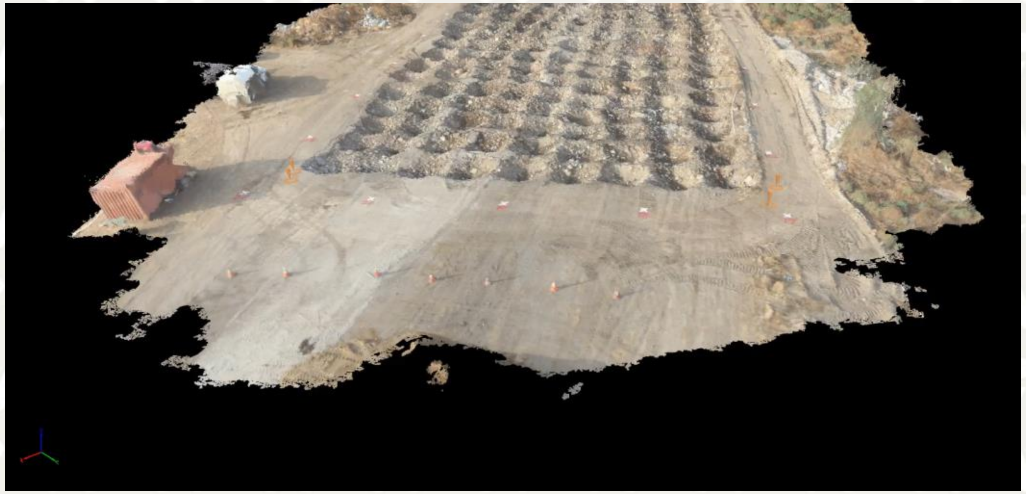
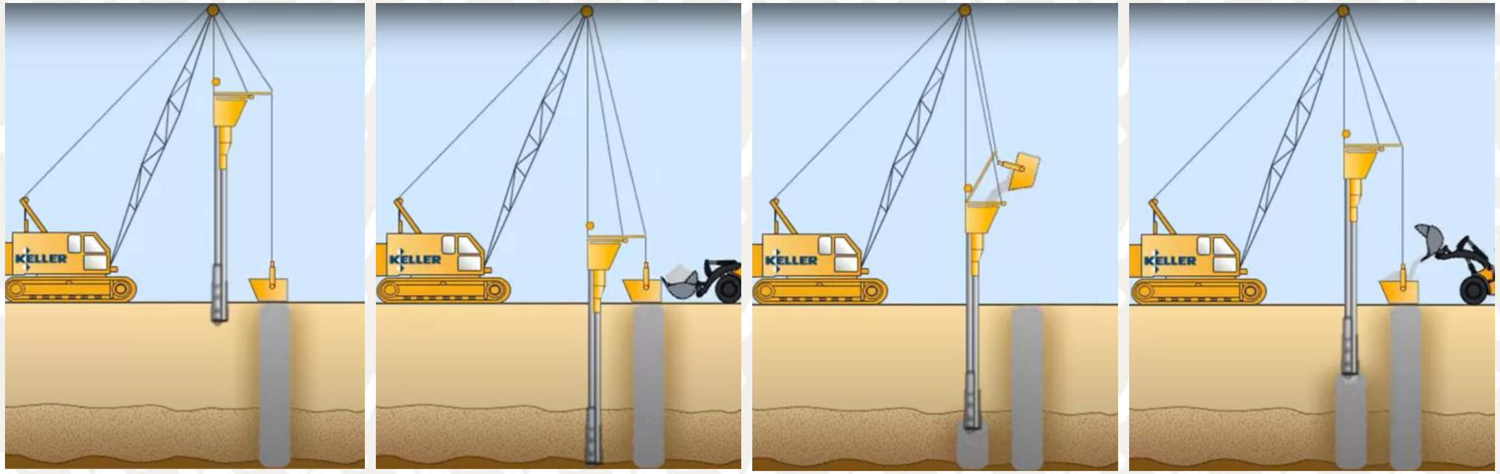
Quality assurance is typically done with borehole sampling or CPTs, in conjunction with volume and site surface settlement measurements

Burbank CA. Performed by Hayward Baker, Now Keller



Vibro Stone Columns

Emerging System



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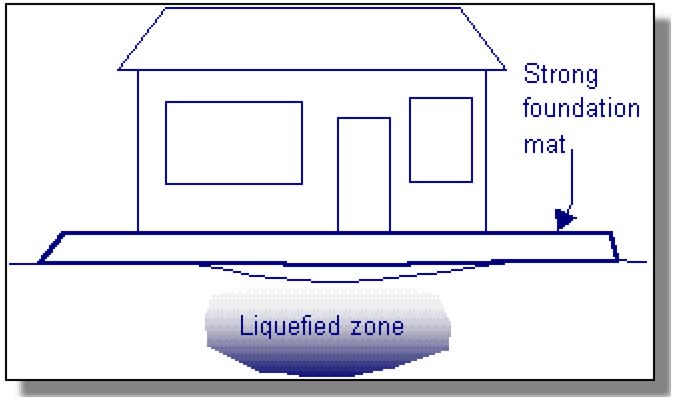
Mat Foundations

Pros:
-Reduction in differential settlement
-Can carry large loads

Cons:
-Does not mitigate for excessive settlement if entire mat is within liquefiable zone

-Expensive because of the amount of concrete and rebar needed

Quality assurance obtained by concrete testing (ex. slump test, concrete cylinders)



Buried utilities, such as sewage and water pipes, should have ductile connections to the structure to accommodate the large movements and settlements that can occur due to liquefaction. The pipes in the photo connected the two buildings in a straight line before the earthquake (KG).

https://depts.washington.edu/liquefy/html/how/resistantstructures.html

Building Performance Example
(Buildings on Piles and Mat Foundations)

Building on mat foundation.
Building settled and tilted.
However, no observable damage
to the structure

Figure 5-27. Settlement of ground around pile supported structure: (a) 20 cm, position 3; (b) 25 cm, position 4; (c) 25 cm, position 6; (d) 25 cm, position 7. (Position locations shown in Figure 5-23.)

Building on piles (street settled relative to the pile-supported building)

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