Liquefaction Evaluations and Mapping

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University of Utah Asia Campus

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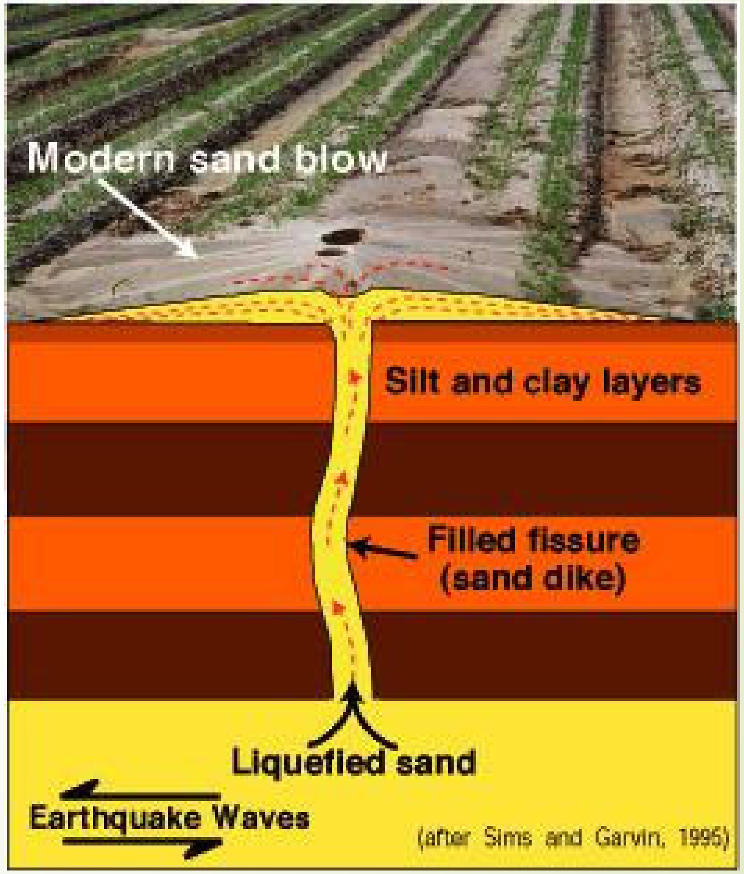
Background

- B.S. Degree (1983) Brigham Young University
- Ph.D. Degree (1988 -1992) Brigham Young University
  - Dr. T. Leslie Youd (Advisor)
  - Empirical Analysis of Liquefaction-Induced Lateral Spread
- Westinghouse Savannah River Co. (1991 – 1996)
  - Seismic and Liquefaction Evaluations of Nuclear Facilities
- Woodward-Clyde Consultants (1996-1998)
  - Liquefaction Evaluations for I-15 Interstate Reconstruction for 2002 Winter Olympic Games – Salt Lake City, Utah
- Research Engineer – Utah Department of Transportation (1999)
- University of Utah (2000 – present)

Topics

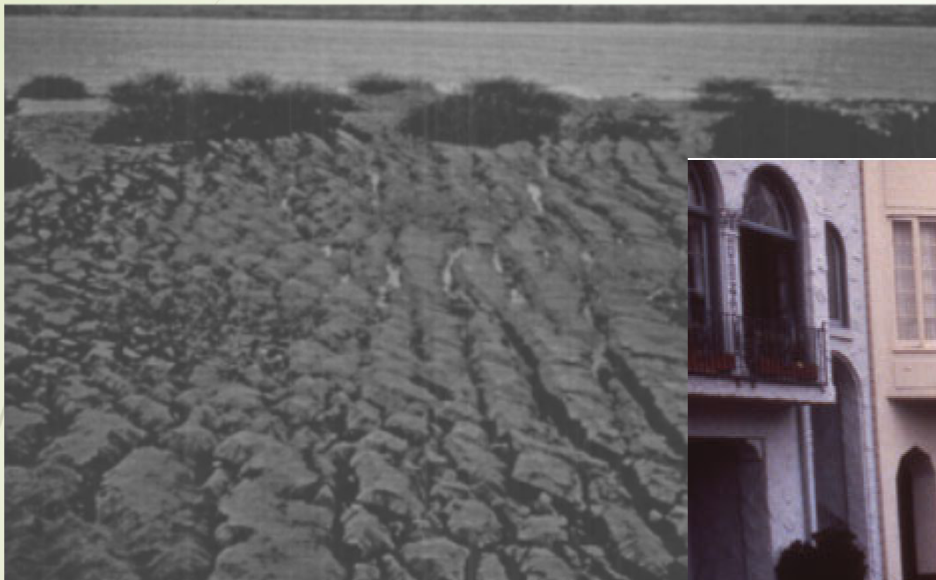
- Liquefaction Effects
- Liquefaction Evaluations
- Liquefaction Research
- Liquefaction Maps
- Liquefaction Hazard Assessment
- Pipeline Protection
- Seismic Buffers
- Unreinforced Masonry (URM) Retrofitting

Liquefaction Effects



Sand Blow or Sand Volcano

Liquefaction Effects



Ground Oscillation

Marina District, San Francisco, 1989 Loma Prieta Earthquake

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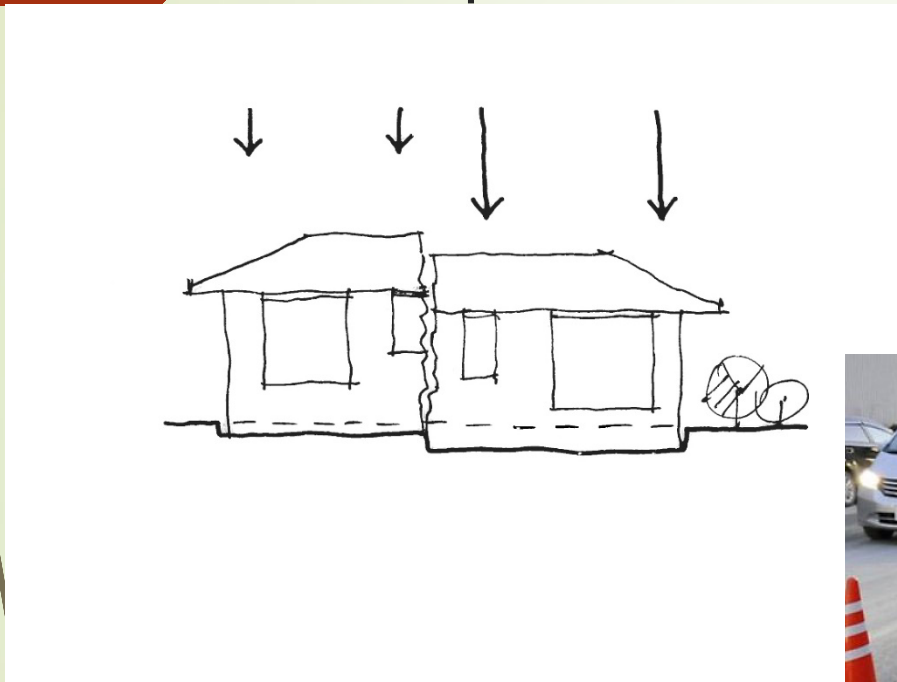
Liquefaction Effects



Ground Settlement

2011 Tohoku, Japan Earthquake

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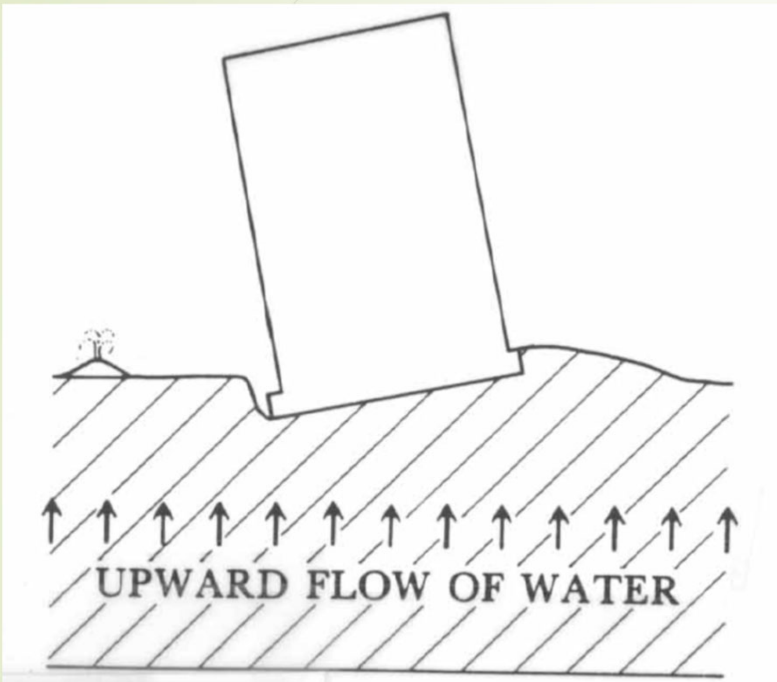
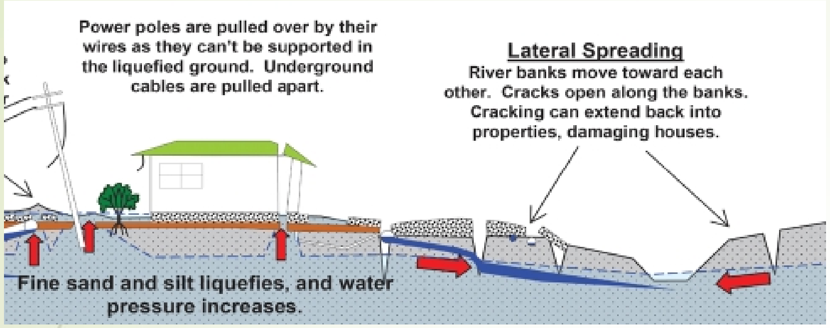
Liquefaction Effects



Bearing Capacity Failure

1964 Niigata, Japan Earthquake

Liquefaction Effects



2011 Tohoku, Japan

Lateral Spread

1964 Niigata, Japan Earthquake

Port of Kobe, 1995 Kobe, Japan Earthquake

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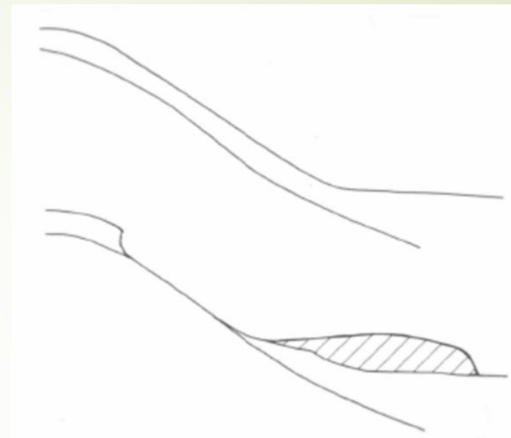
Liquefaction Effects



Valdez, 1964
Alaska
Earthquake

Flow Failure

Palu, 2018 Indonesian
Earthquake

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Topics

- Liquefaction Effects
- **Liquefaction Evaluations**
- Liquefaction Research
- Liquefaction Maps
- Liquefaction Hazard Assessment
- Pipeline Protection
- Seismic Buffers
- Unreinforced Masonry (URM) Retrofitting

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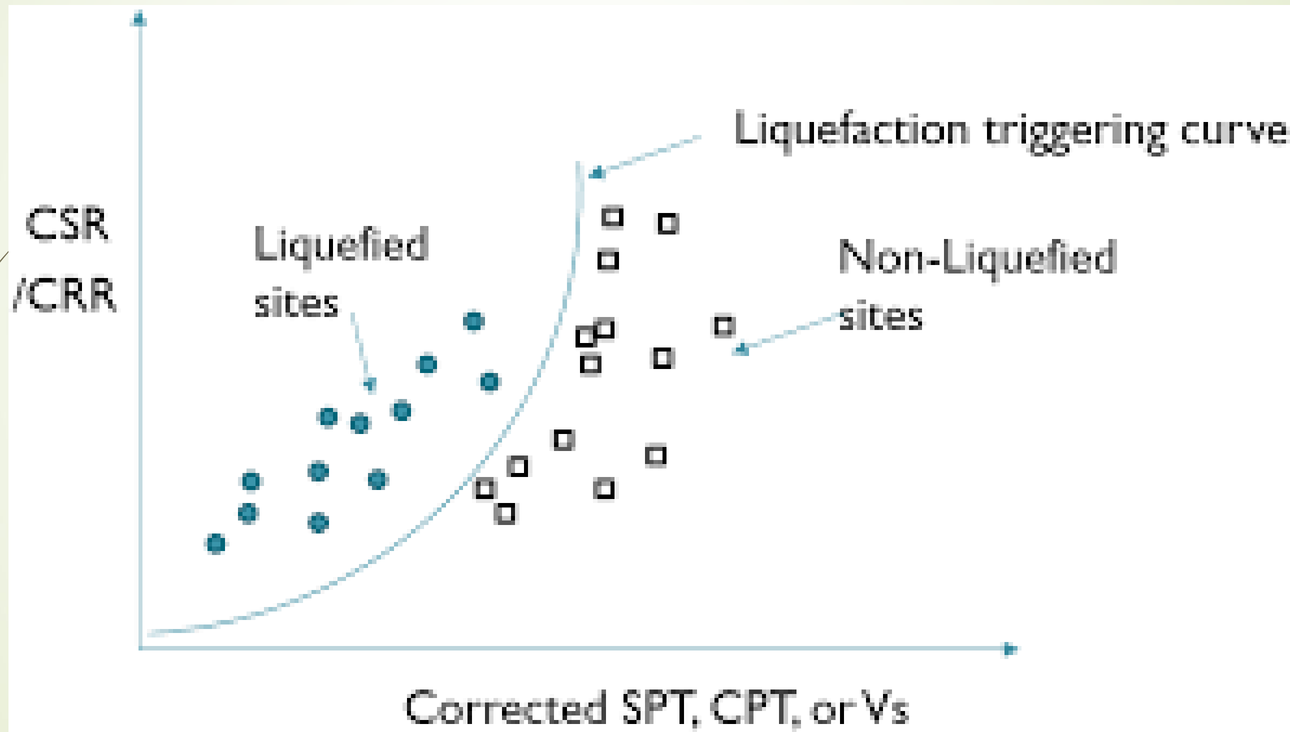
Liquefaction Evaluations

1. Three questions must be assessed when evaluating the liquefaction hazard of a given site.
   i) Is the soil potentially susceptible to liquefaction?
   ii) If potentially susceptible, will liquefaction be triggered by an earthquake event”
   iii) If liquefaction is triggered, what will be the consequences of liquefaction (i.e., what are the consequences and the potential magnitude of displacement?

Liquefaction Evaluation Methods



Liquefaction Triggering Curves

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Liquefaction Evaluations

- SPT method
- CPT method
- Vs method

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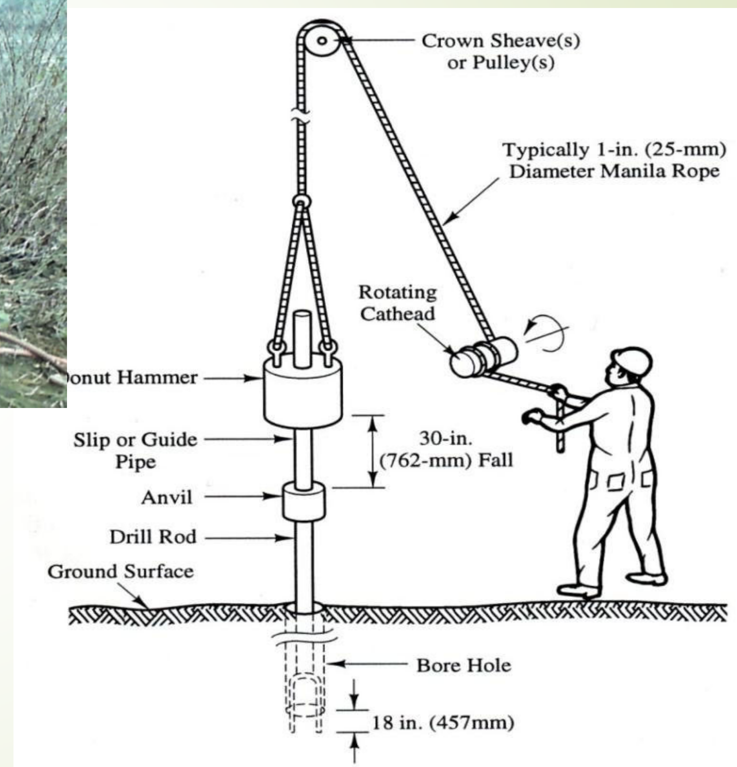
SPT methods

Mud Rotary Drilling



Standard Penetration Test

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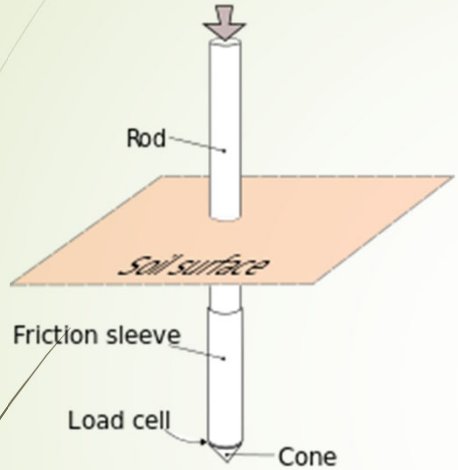
CPT Methods



Cone Penetrometer Test

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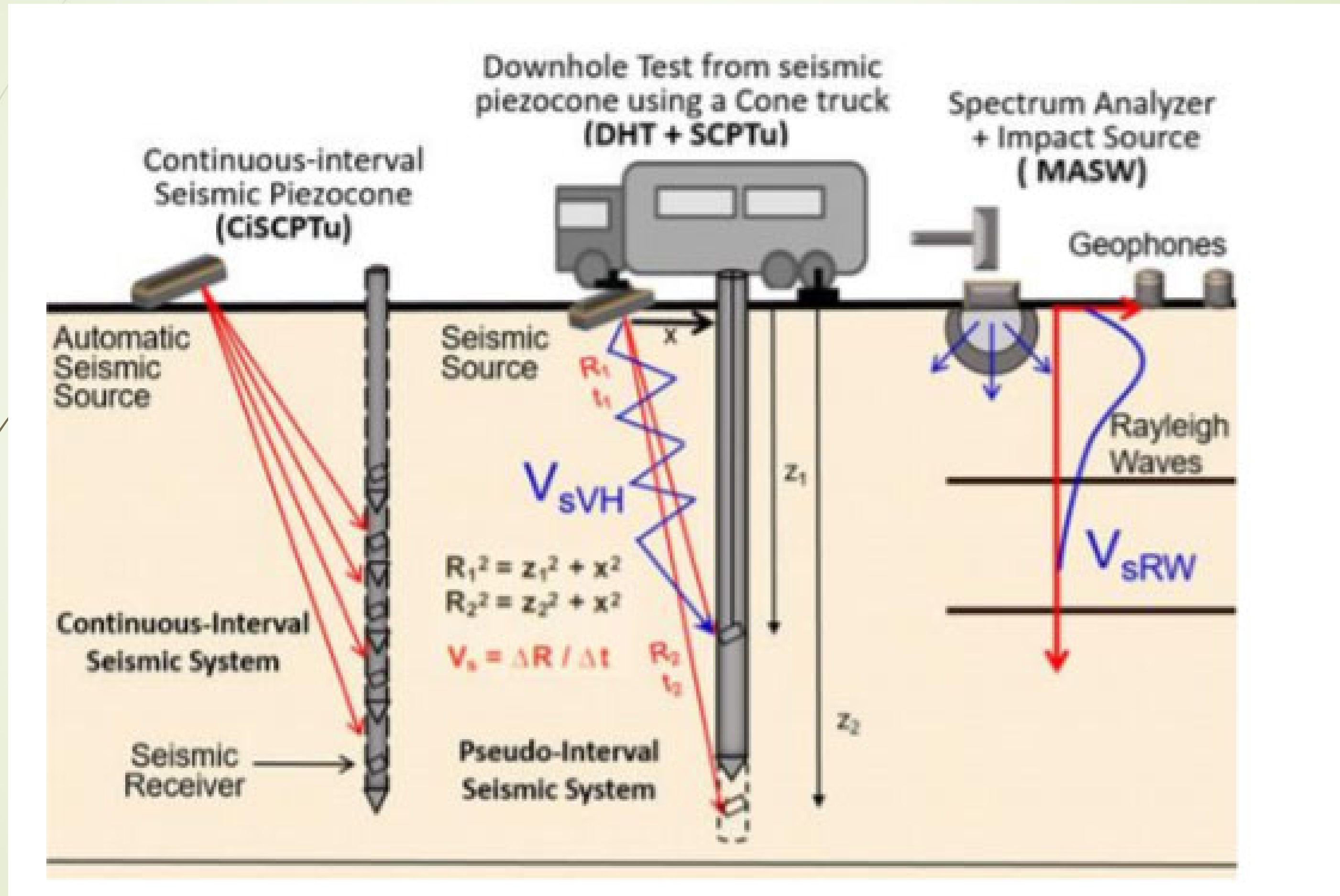
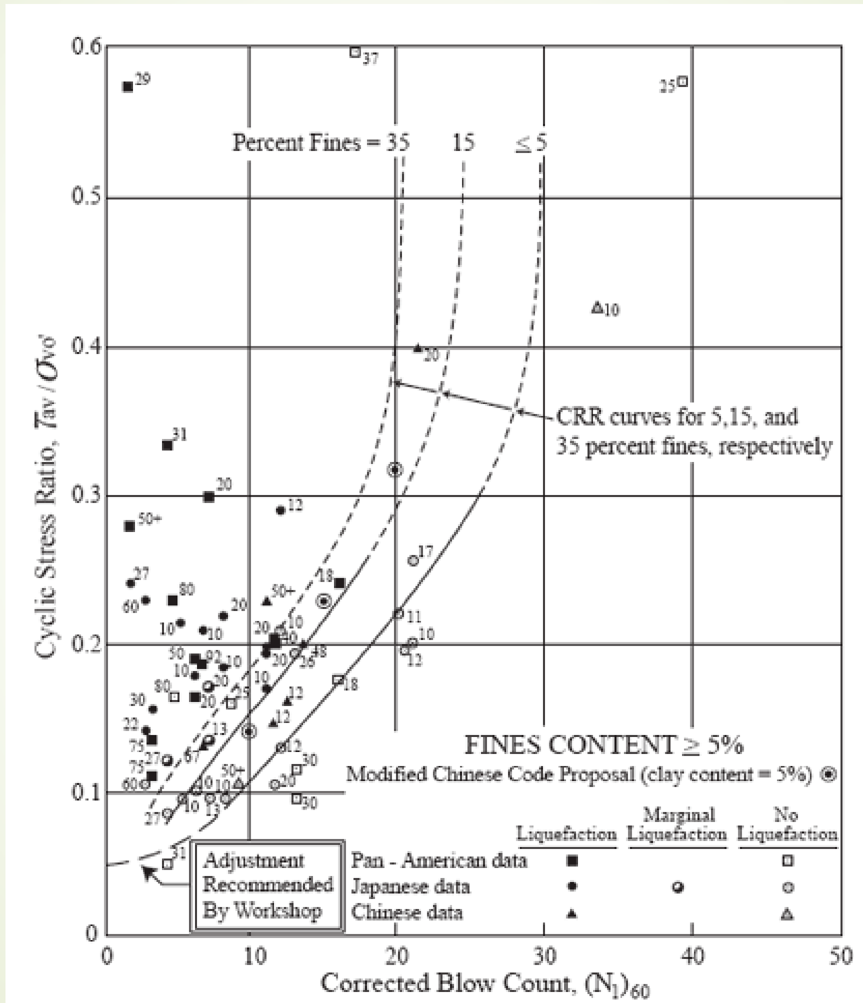
Vs Testing



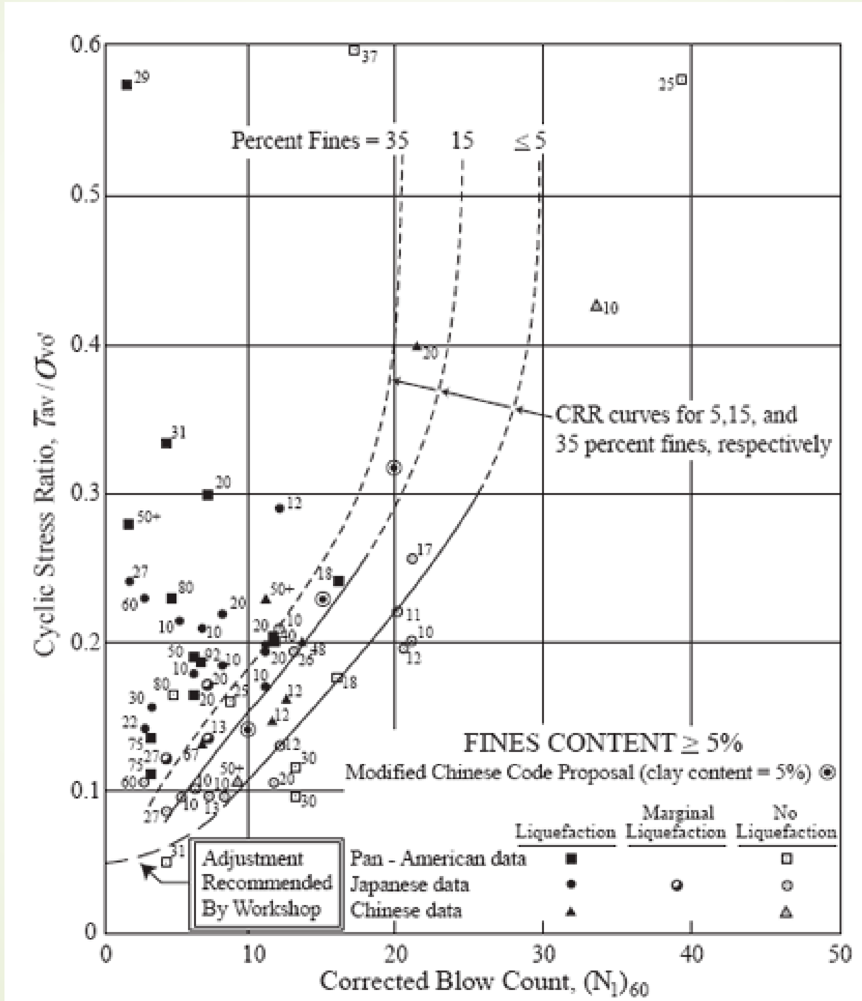
Shear Wave Velocity, Vs, Test

SPT Liquefaction Curves



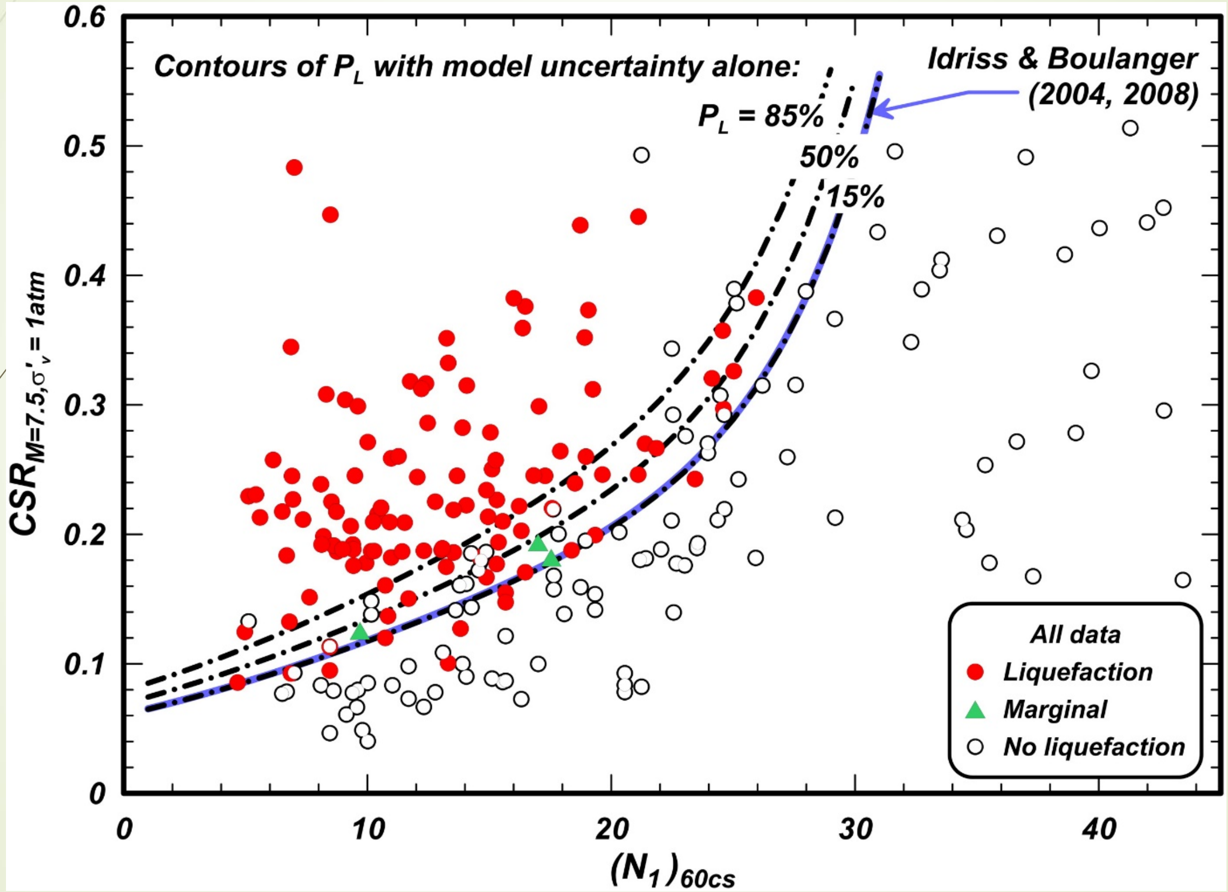
Seed, Idriss and Arango

SPT Liquefaction Curves



Seed, Idriss and Arango

SPT Liquefaction Curves



Idriss and Boulanger

Topics

- Liquefaction Effects
- Liquefaction Evaluations
- **Liquefaction Research**
- Liquefaction Maps
- Liquefaction Hazard Assessment
- Pipeline Protection
- Seismic Buffers
- Unreinforced Masonry (URM) Retrofitting

Liquefaction Research

Pacific Earthquake Engineering Research (PEER) – Development of Next Generation Liquefaction (NGL) Database for Liquefaction-Induced Lateral Spread

Lateral Spread Research Team

- University of Utah, Steven Bartlett (Lead)
- University of Washington, Steven Kramer
- Brigham Young University, Kevin Franke
- NOAA, Daniel Gillins (Consultant)

https://peer.berkeley.edu/ngl

PEER

Goals of PEER NGL Project

1. **improve** the quality, transparency, and accessibility of **case history data** related to ground failure;
2. provide a **coordinated framework** for supporting studies to **augment case history** data for conditions important for applications but poorly represented in empirical databases;
3. provide an **open, collaborative process for model developmen**t in which developer teams have access to common resources and share ideas and results during model development, so as to reduce the potential for mistakes and to mutually benefit from best practices.

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Project Objectives

1. Develop **peer-reviewed and consistent methodology** for data documentation and archiving of lateral spread case histories.
2. Develop **quality assurance protocols** for assessing and documenting data quality.
3. Develop methods and/or protocols to **quantify uncertainties associated with the collected data**.
4. Populate the case history database with **well-documented examples of liquefaction-induced lateral spread**.
5. Review **screening criterion** used in evaluating lateral spread potential.
6. Disseminate **the database for general use** using web-based software

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Types of Data in Database

- Seismological Factors
- Topographical Factors
- Geotechnical / Soil Factors
- Damage and Ground Displacement Data

Seismological Factors

Earthquake Name and Year
Earthquake Magnitude, Mw
Location
Source Distance Measures, Rrup, Rjb, etc.
Peak Ground Acceleration
Other measures of intensity (MMI, spectral accelerations, etc.
Duration
Nearby accelerogram (if available)

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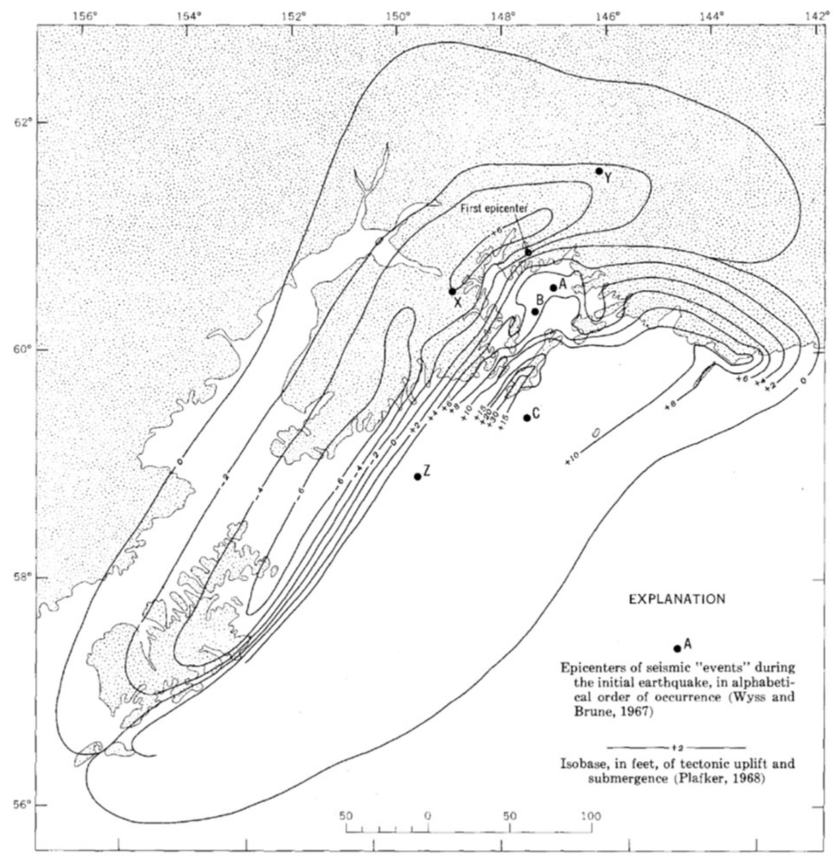
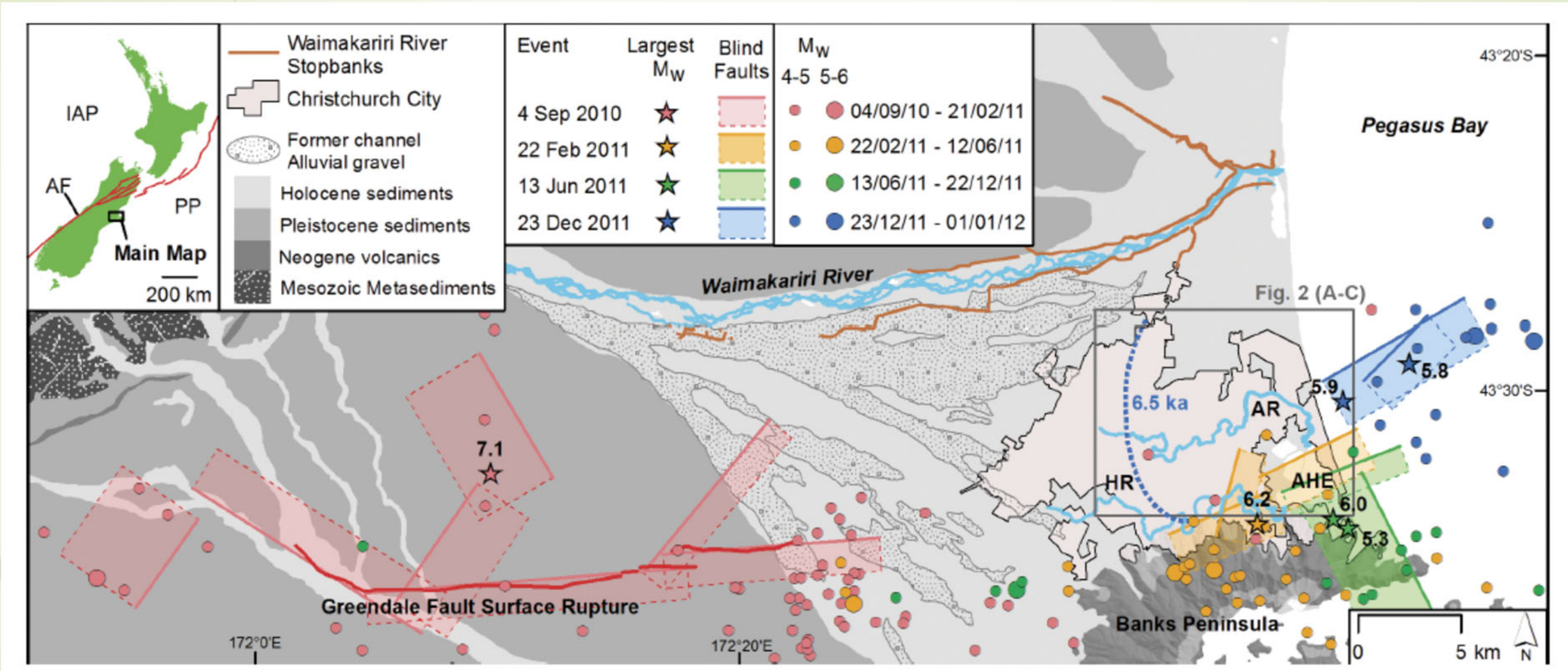
Seismological Factors



2.—Location of the epicenters of recognizable seismic events that occurred during the earthquake (Wyss and Brune, 1967) and areas of tectonic uplift and subsidence in south-central Alaska (Plafker, 1968).

Epicenters and Crustal Warping - 1964 Alaska Earthquake

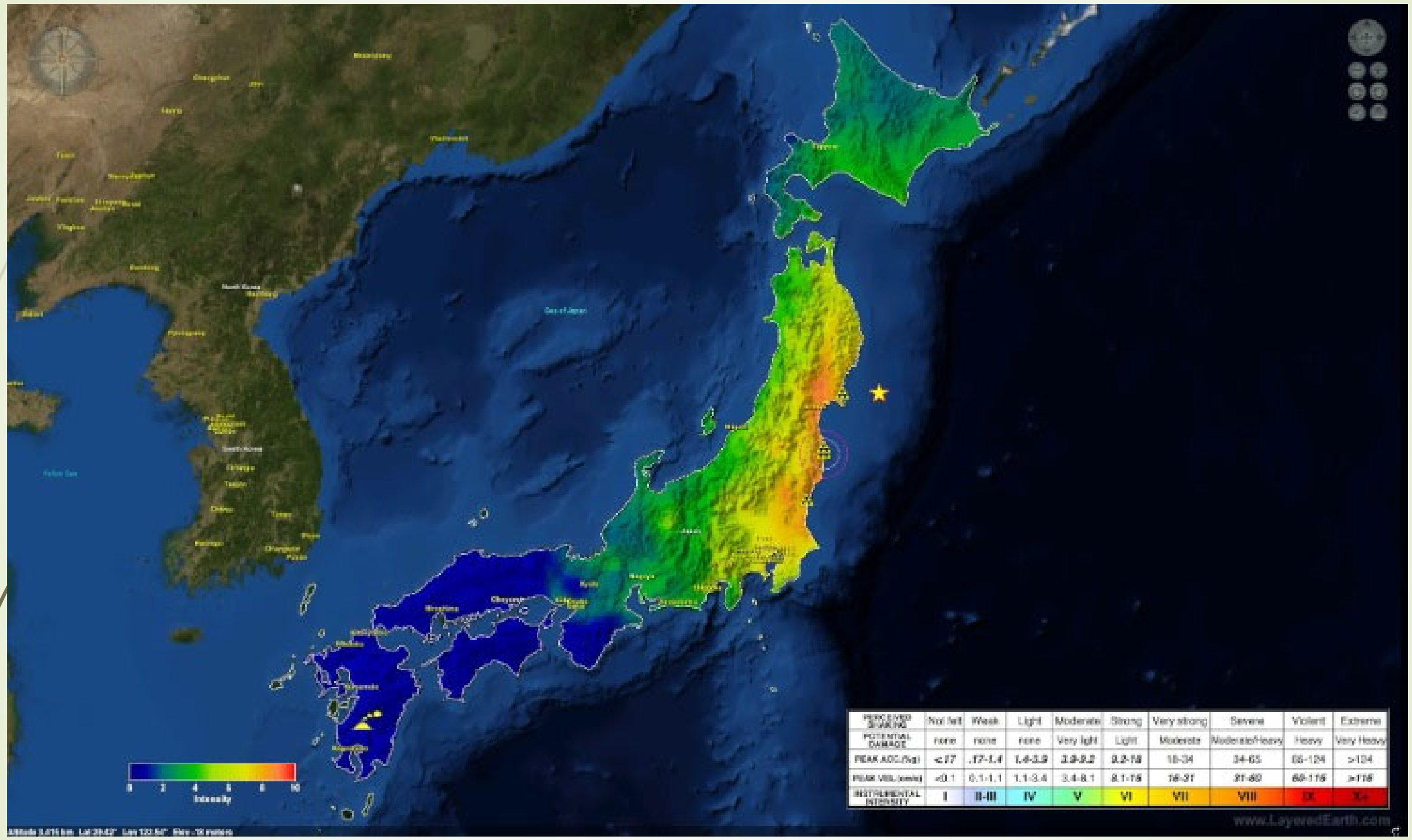
Seismological Factors



GSA Today, v. 25, no. 3–4, doi: 10.1130/GSATG221A.1.

Geological and Seismological Context of Seismicity in Christ Church, New Zealand

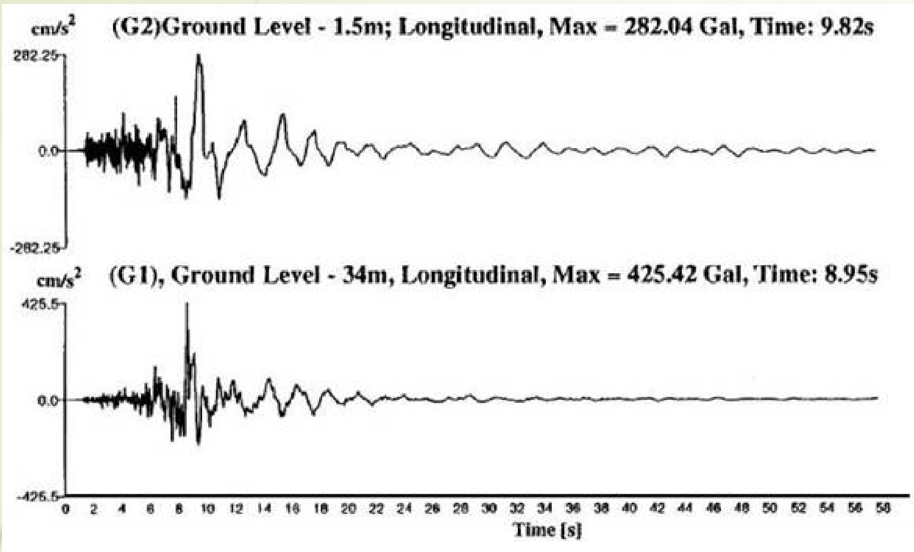
Seismological Factors



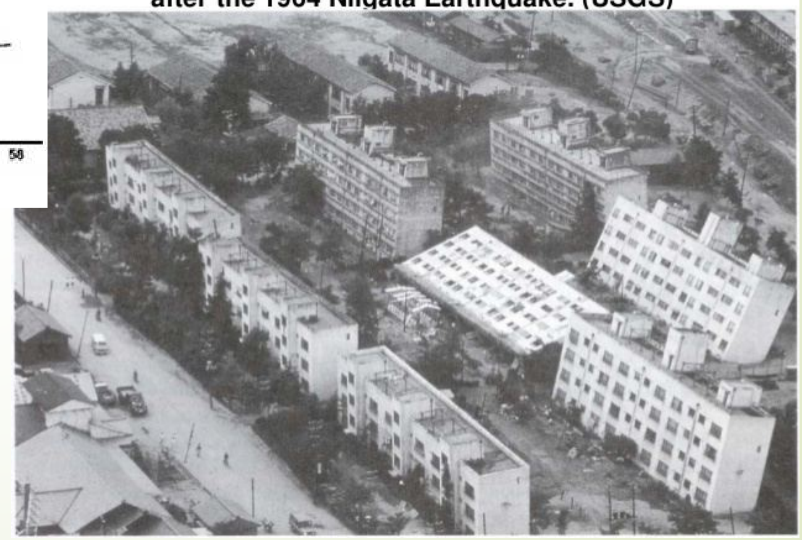
Earthquake Strong Motion Map

2011 Honshu Earthquake

Seismological Factors



Dynamic: Foundation failure by liquefaction after the 1964 Niigata Earthquake. (USGS)



1964 Niigata Japan Earthquake

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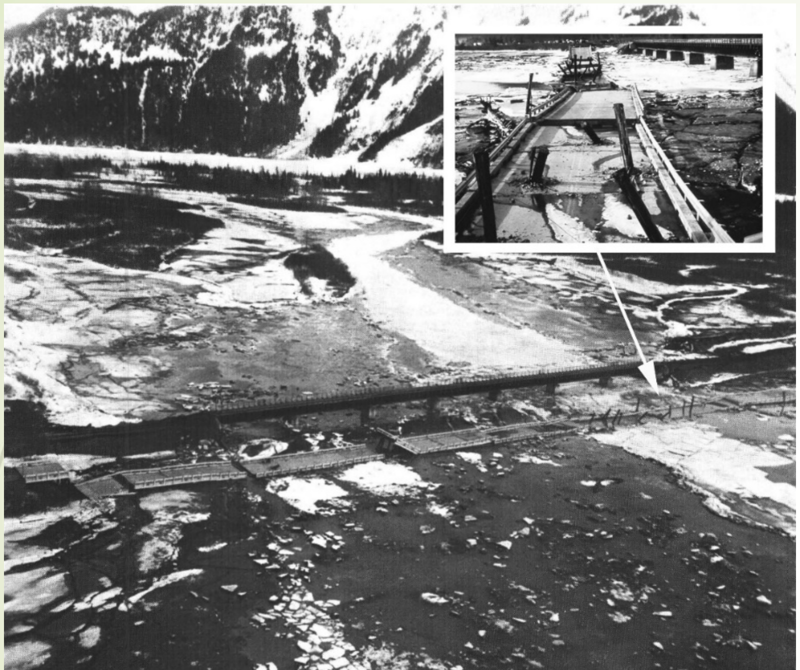
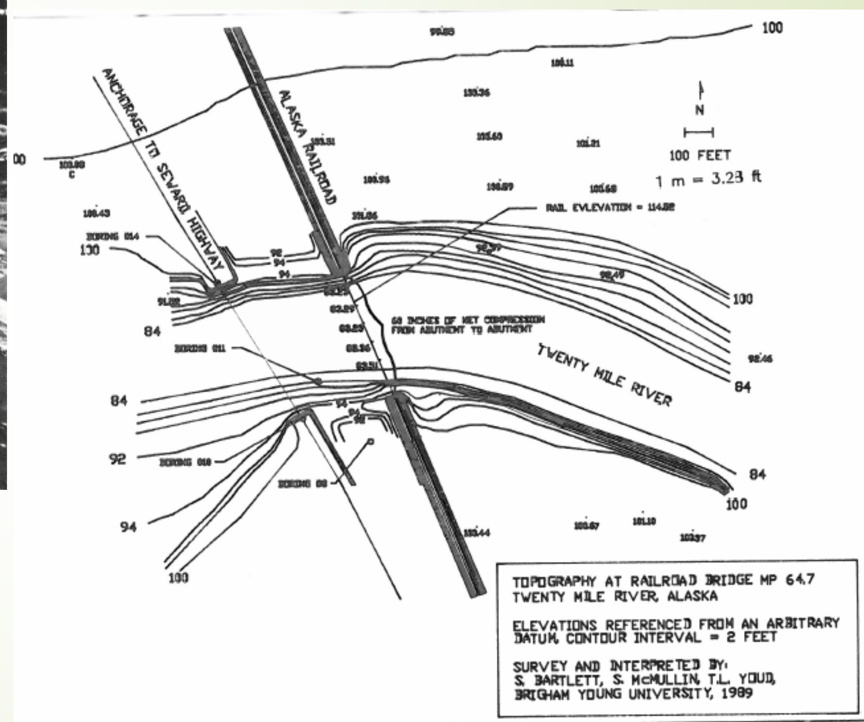
Topographical Factors



20 Mile River - 1964
Alaska Earthquake



Geotechnical / Soil Factors

Geological unit and type of sediments
Age of sediments
Depth to groundwater
Geological map (if available)

Geotechnical / Soil Factors

TABLE 8-1
SUSCEPTIBILITY OF SEDIMENTARY DEPOSITS TO LIQUEFACTION DURING STRONG SHAKING
(After Youd and Perkins, 1978, Reprinted by Permission of ASCE)

Type of Deposit	General Distribution of Cohesionless Sediments in Deposits	Likelihood that Cohesionless Sediments, When Saturated, Would Be Susceptible to Liquefaction (by Age of Deposit)			
		<500 Year	Holocene	Pleistocene	Pre-pleistocene
Continental Deposits					
River channel	Locally variable	Very high	High	Low	Very low
Flood plain	Locally variable	High	Moderate	Low	Very low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very low
Marine terraces and plains	Widespread	—	Low	Very low	Very low
Delta and fan-delta	Widespread	High	Moderate	Low	Very low
Lacustrine and playa	Variable	High	Moderate	Low	Very low
Colluvium	Variable	High	Moderate	Low	Very low
Talus	Widespread	Low	Low	Very low	Very low
Dunes	Widespread	High	Moderate	Low	Very low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very low	Very low
Tuff	Rare	Low	Low	Very low	Very low
Tephra	Widespread	High	High	Unknown	Unknown
Residual soils	Rare	Low	Low	Very low	Very low
Sebka	Locally variable	High	Moderate	Low	Very low

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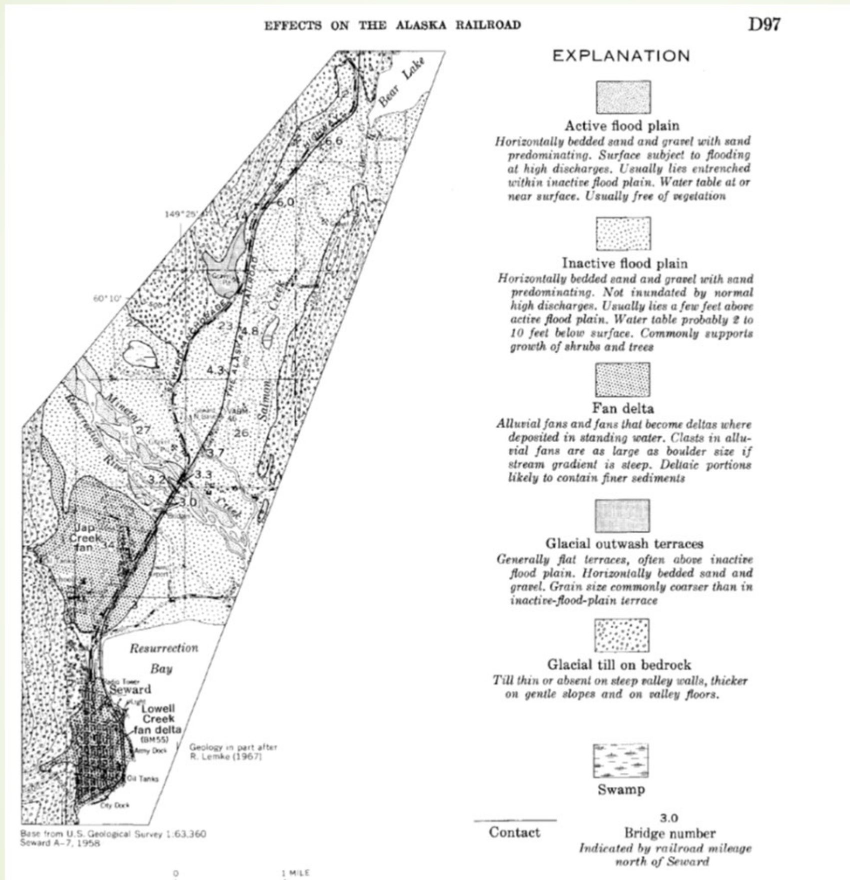
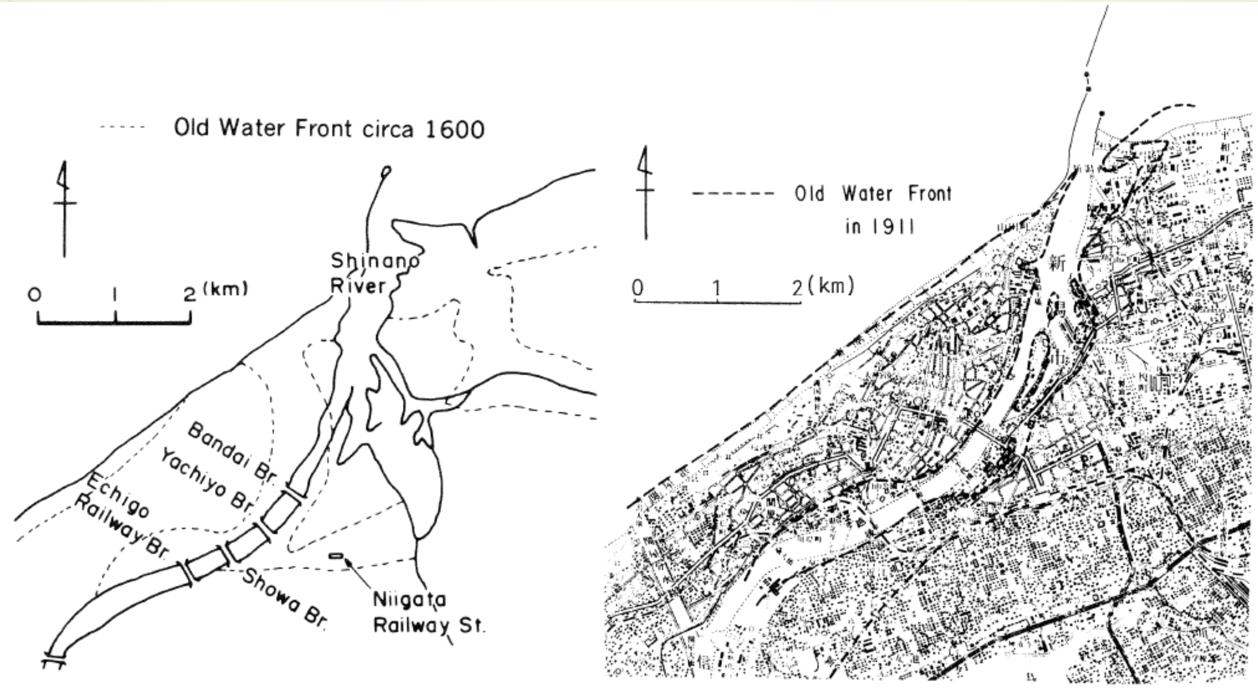
Geotechnical / Soil Factors



Seward Geologic Map - 1964
Alaska Earthquake

Geotechnical / Soil Factors



(a) Old Water Front circa 1600 (b) Old Water Front in 1911

Figure 7. Change of the Shinano River Course

1964 Niigata, Japan Earthquake

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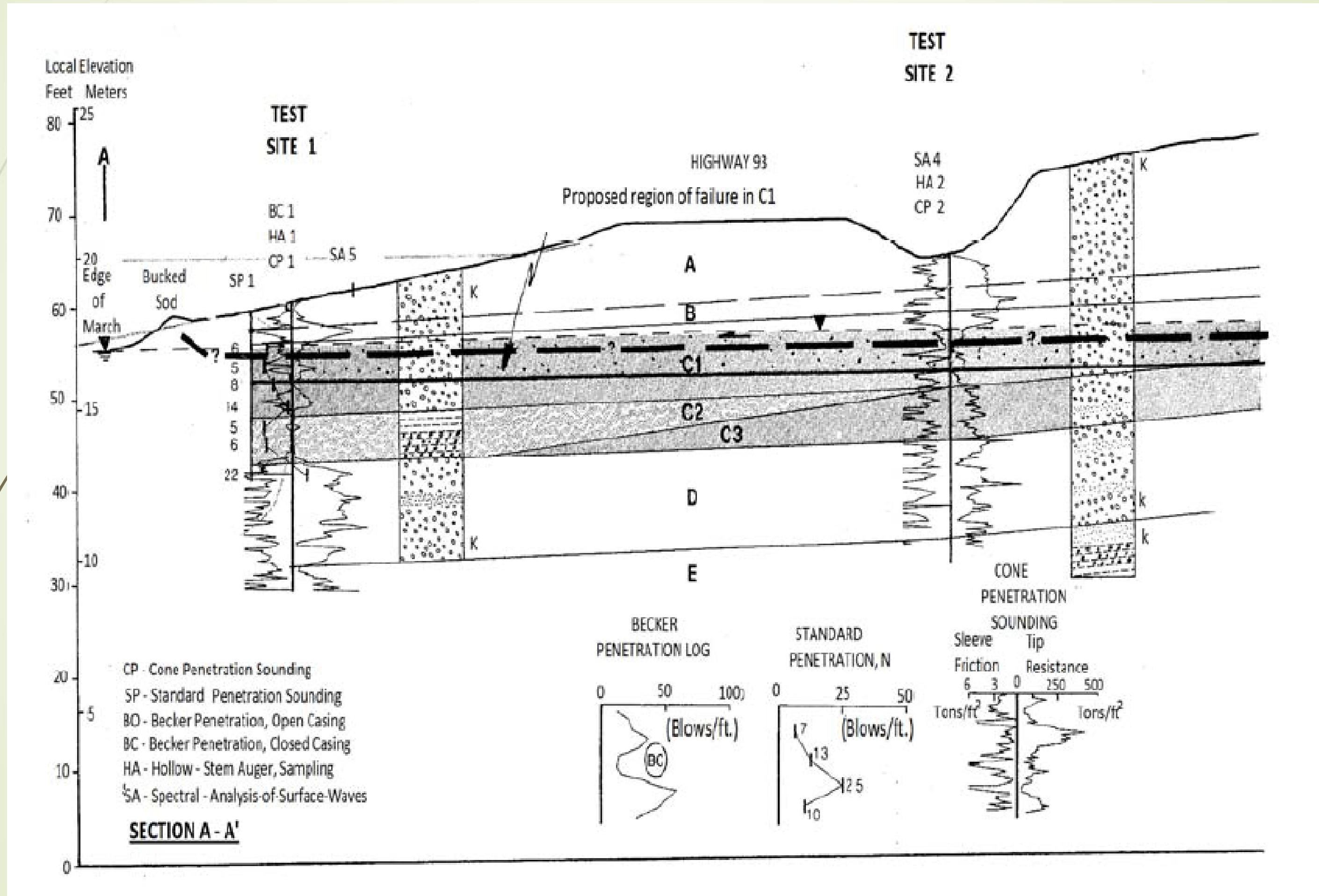
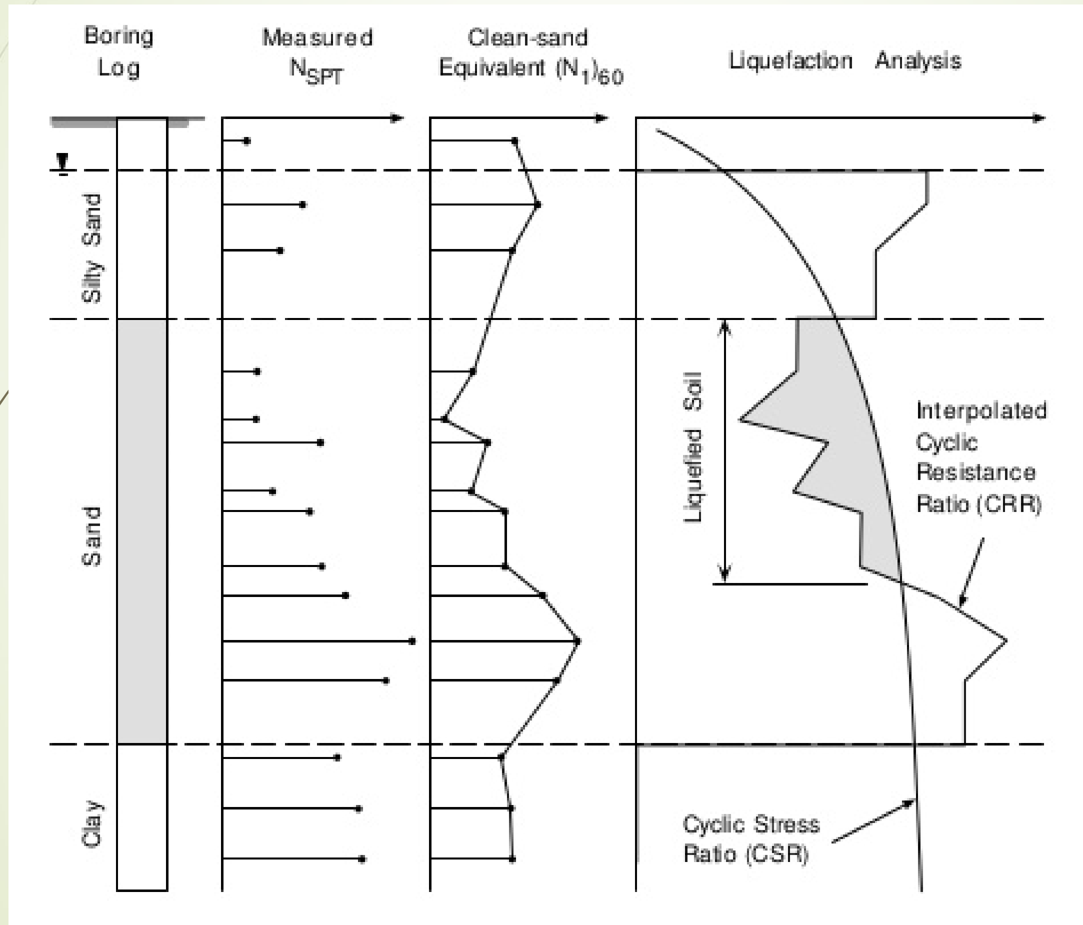
Geotechnical / Soil Factors

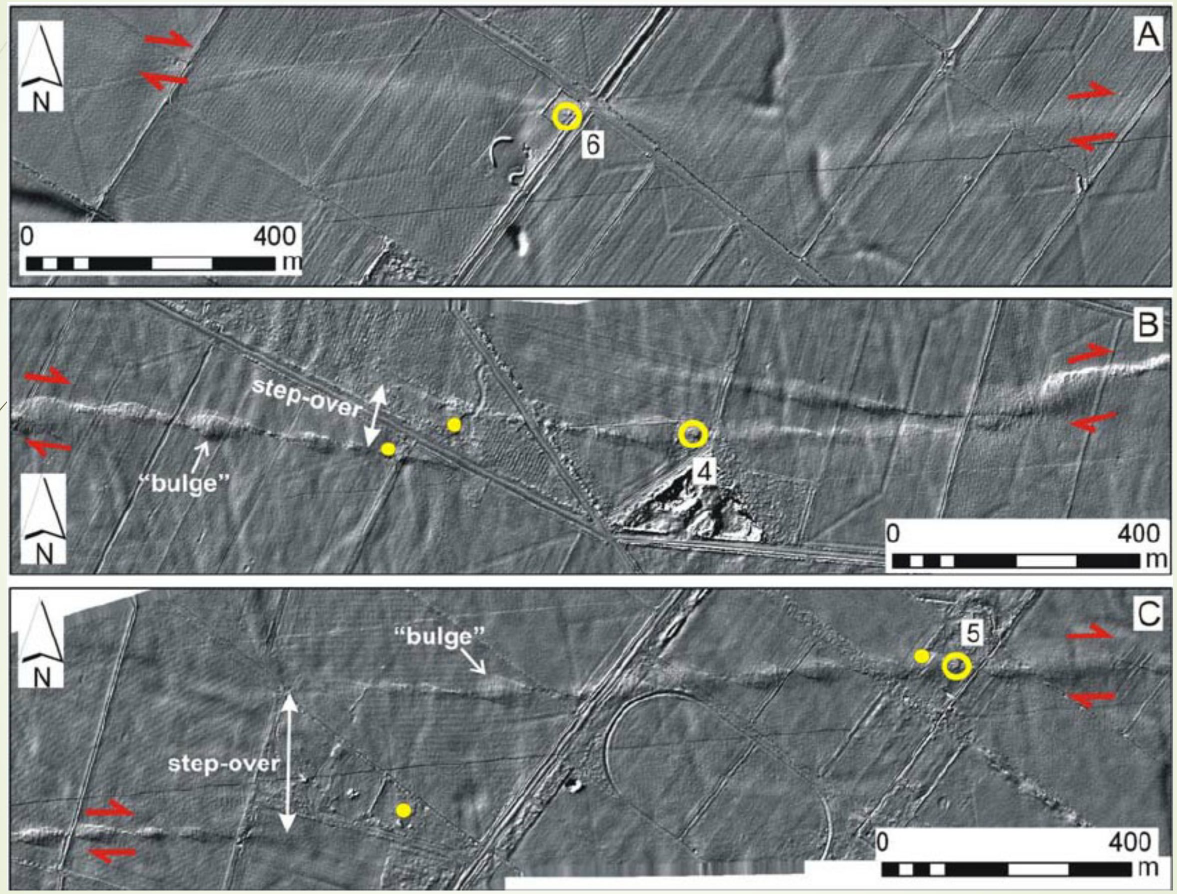


1983 Borah Peak Idaho Earthquake

Geotechnical / Soil Factors



Damage / Ground Displacement



LiDAR hillshade DEMs (illuminated from the NW) of three ~1.8 km long sections of the Greendale Fault – Darfield New Zealand Earthquake

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Damage / Ground Displacement

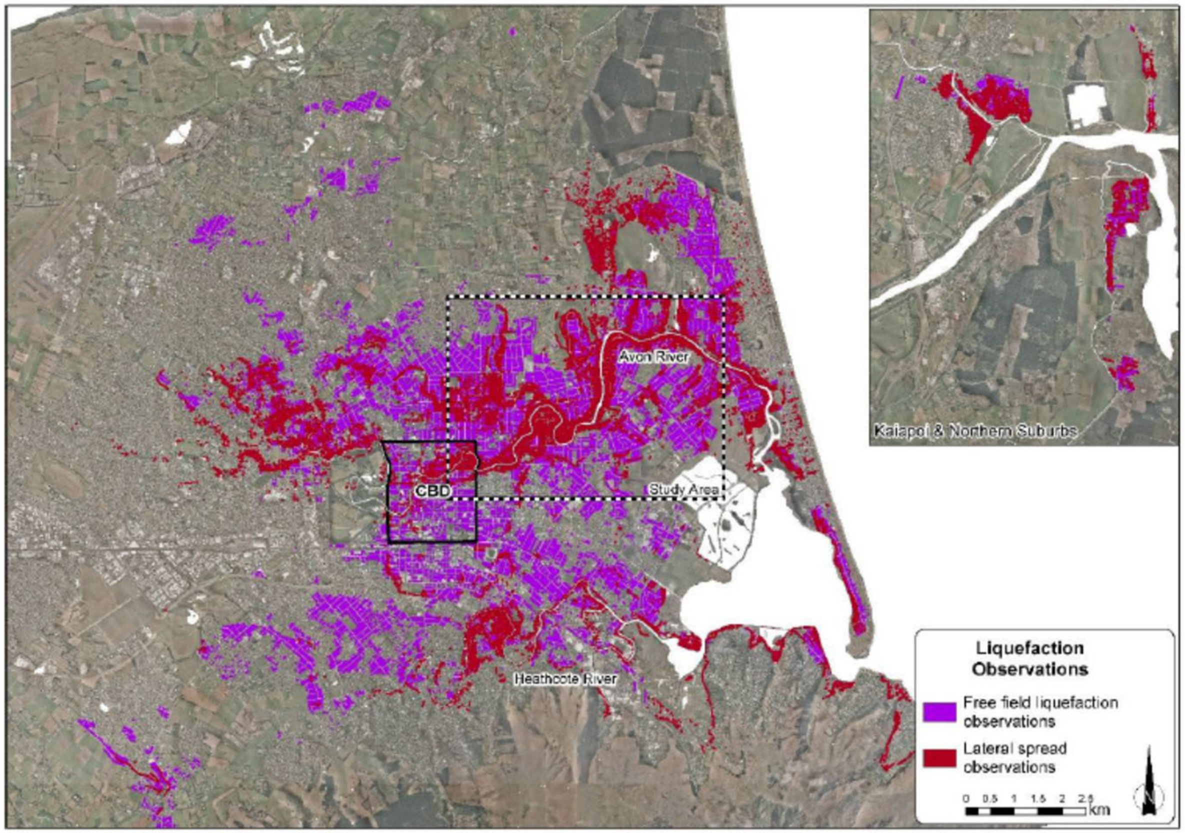
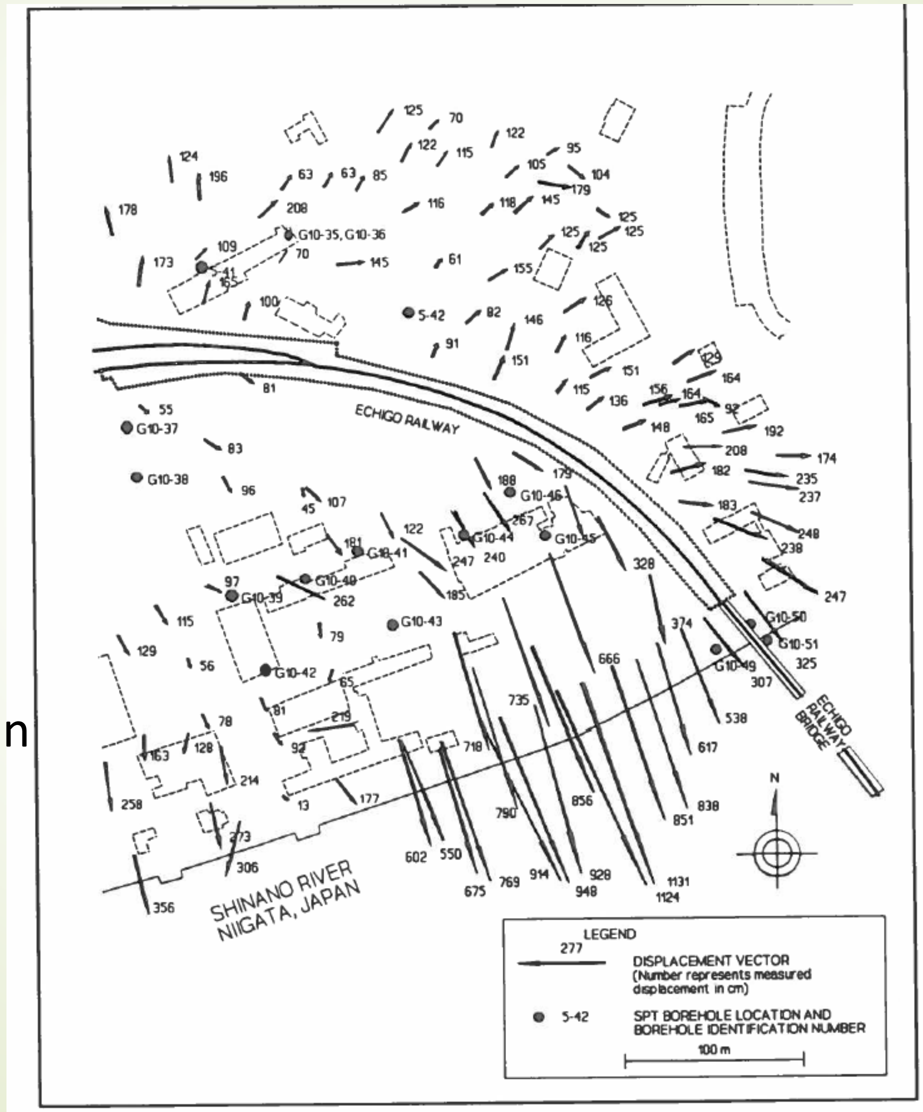


Figure F1.1: Lateral spreading and free field liquefaction observations during the CES. The lateral spreading observations shown include recorded ground cracks[1] and observations of lateral spreading on residential properties[2]. Free field liquefaction observations shown are based on land damage observations on residential properties[2].

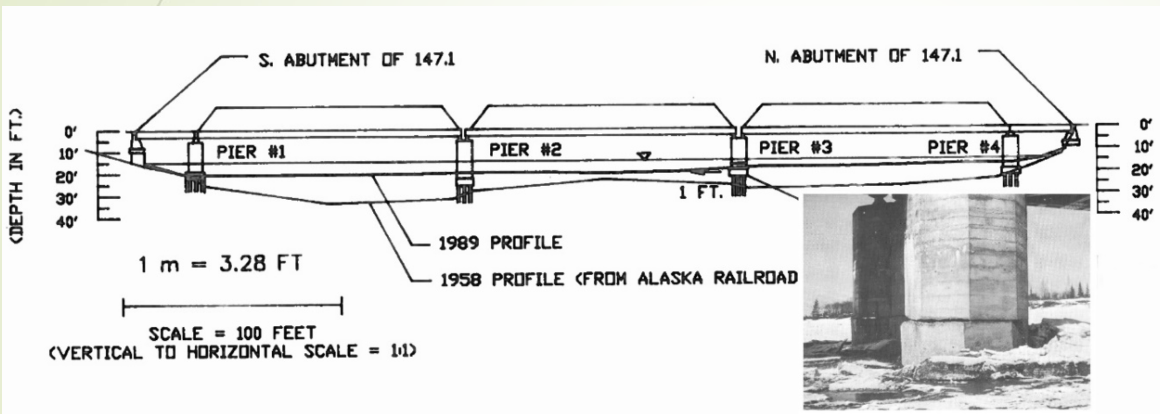
2010 Christ Church Earthquake

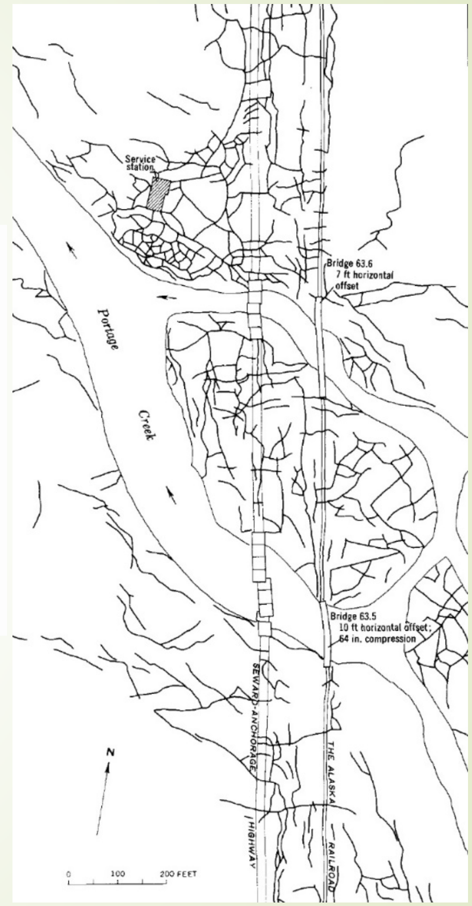
Damage / Ground Displacement



1964 Niigata, Japan Earthquake

Damage / Ground Displacement

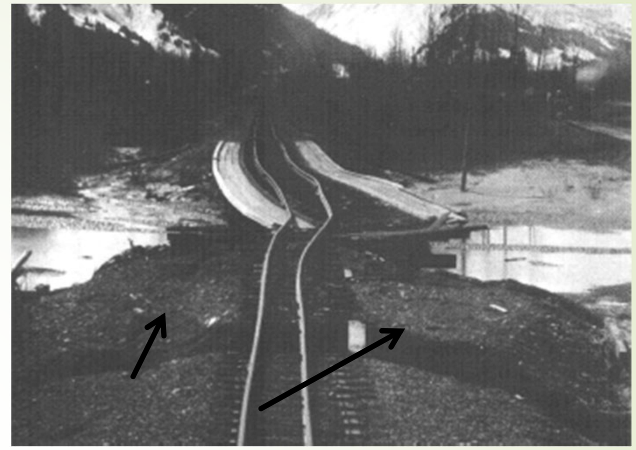




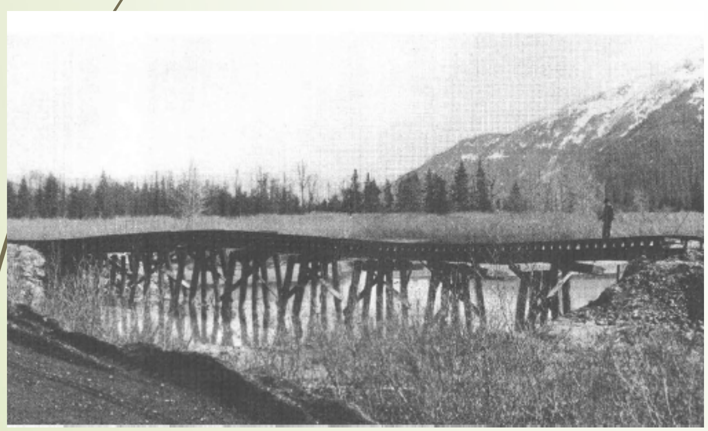
1964 Alaska
Earthquake

Bridge Damage from Lateral Spread

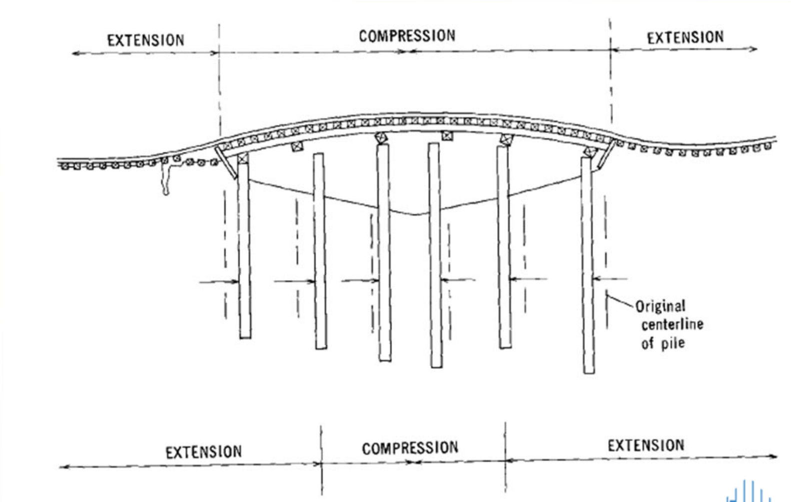
Jack-Knifed Bridge due to Compression



Tensile Crack
Skewed Bridge due to Compression



Differential Settlement and Compression



(McCulloch and Bonilla, 1970)

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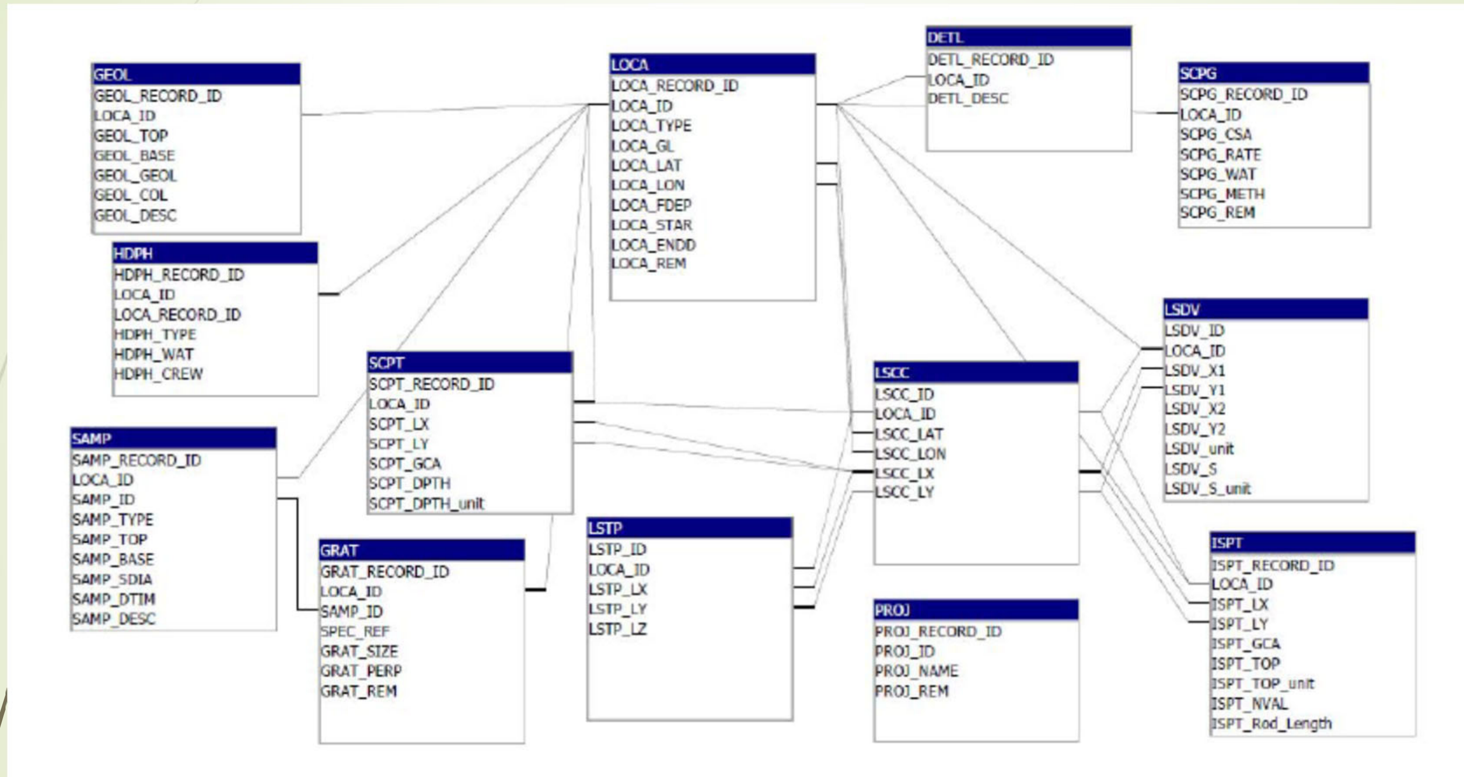
Relational Databases



- Currently in Microsoft Access; could be translated into other database management systems such as MySQL
- Compatible with Electronic Transfer of Geotechnical and Geoenvironmental Data (AGS4) formatting
- Displacement vectors, bore logs, and topology with their spatial coordinates in database
- Other data as flatfiles (or Binary Large Objects, BLOBs)

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Topics

- Liquefaction Effects
- Liquefaction Evaluations
- Liquefaction Research
- **Liquefaction Maps**
- Liquefaction Hazard Assessment
- Pipeline Protection
- Seismic Buffers
- Unreinforced Masonry (URM) Retrofitting

Liquefaction Maps

- Liquefaction Mapping Program funded by the National Earthquake Hazard Program funded by the United States Geological Survey (USGS)
- Began in 2003 and continues till today
- Produce Several Liquefaction and Ground Displacement Maps for Utah
- Serval Mapping Products have been developed

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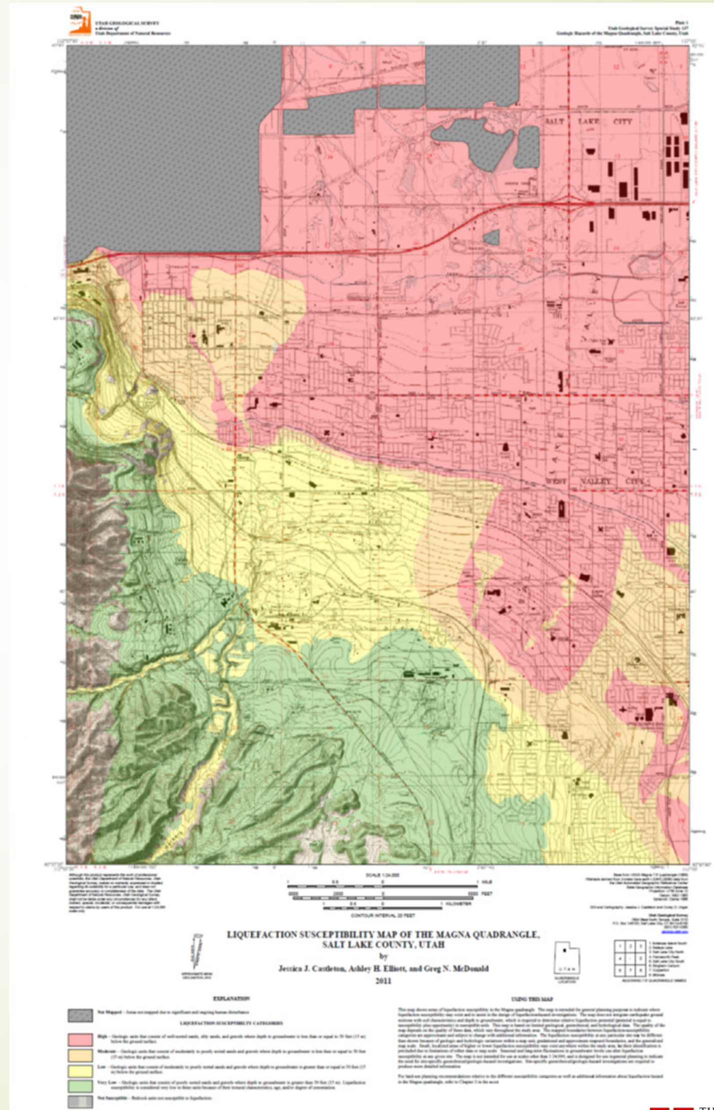
Types of Liquefaction Maps

- **Liquefaction Susceptibility Maps**
- Liquefaction Potential Maps
- Ground Failure Maps

Liquefaction Susceptibility Map

- Liquefaction Susceptibility Maps
  - Show liquefaction hazard based on **susceptibility (soil natural resistance)**, but do not consider demand (size or amplitude of strong ground motion)
  - Usually based on surficial geologic maps with very little to no subsurface information



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Types of Liquefaction Maps

- Liquefaction Susceptibility Maps
- **Liquefaction Potential Maps**
- Ground Failure Maps

Estimation of Liquefaction Potential

$$P(L) = \sum P[L \mid A,M]\ P[A, M]$$

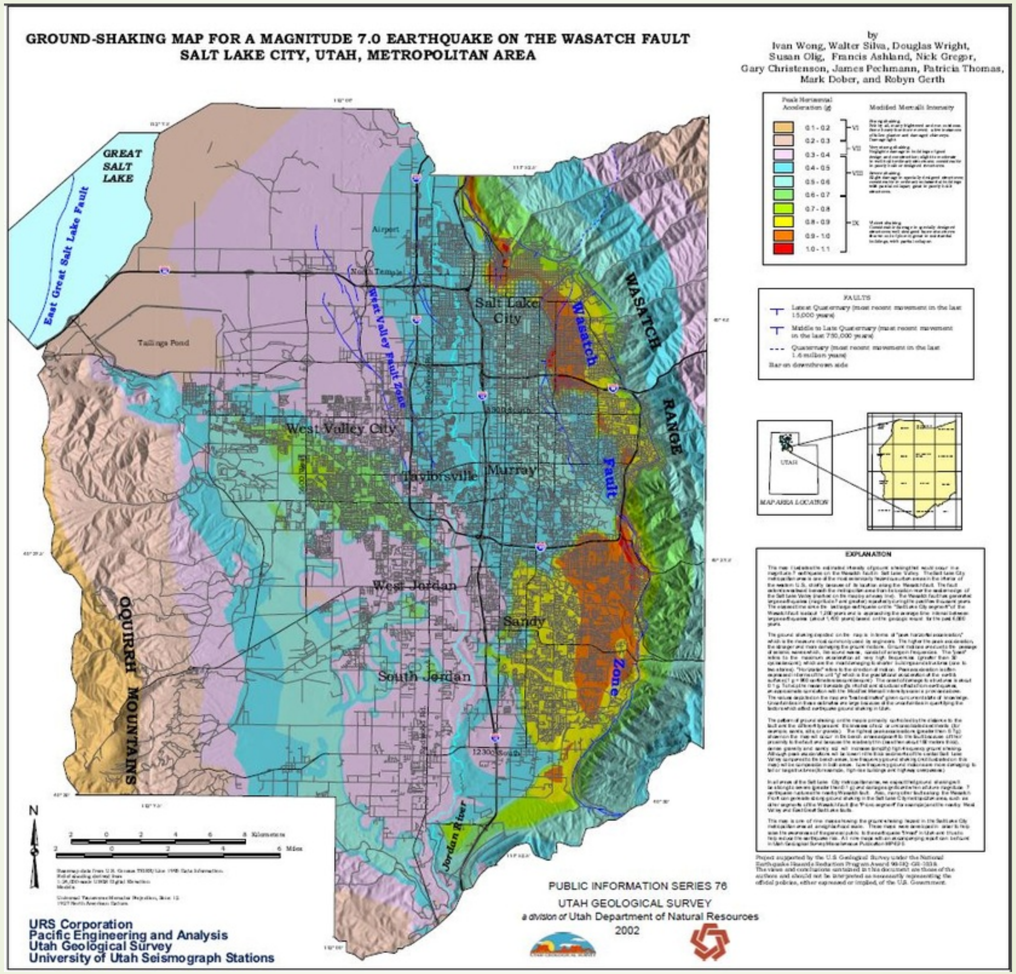
where:

P(L) = annual probability of liquefaction

P [L | A,M] = conditional probability of liquefaction given the peak ground acceleration and the earthquake magnitude,

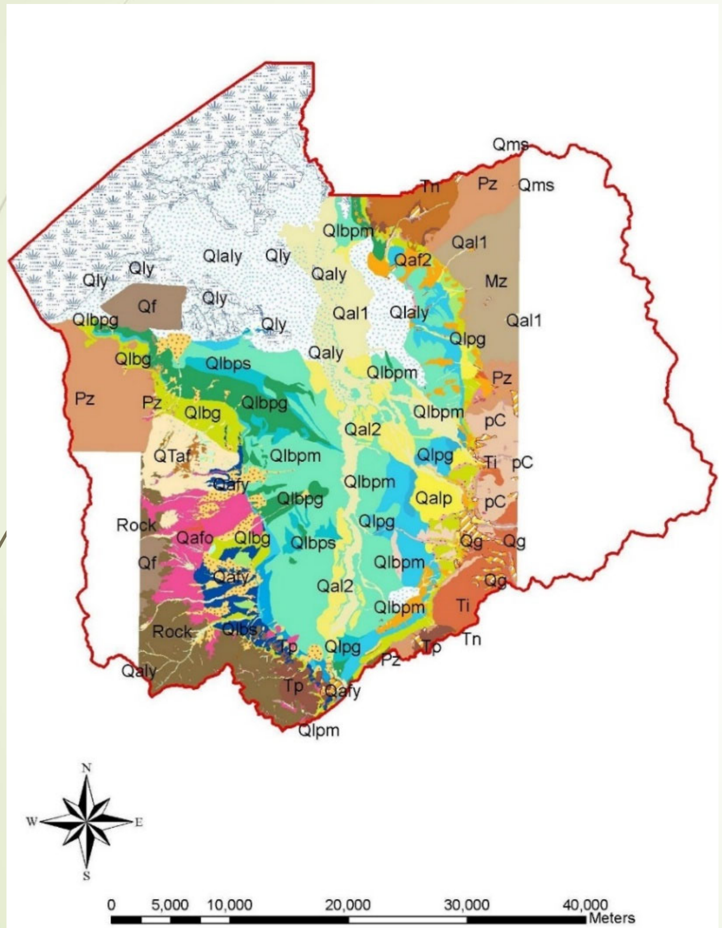
P [A, M] = joint probability density function of peak ground acceleration and earthquake magnitude.

Estimation of Liquefaction Potential

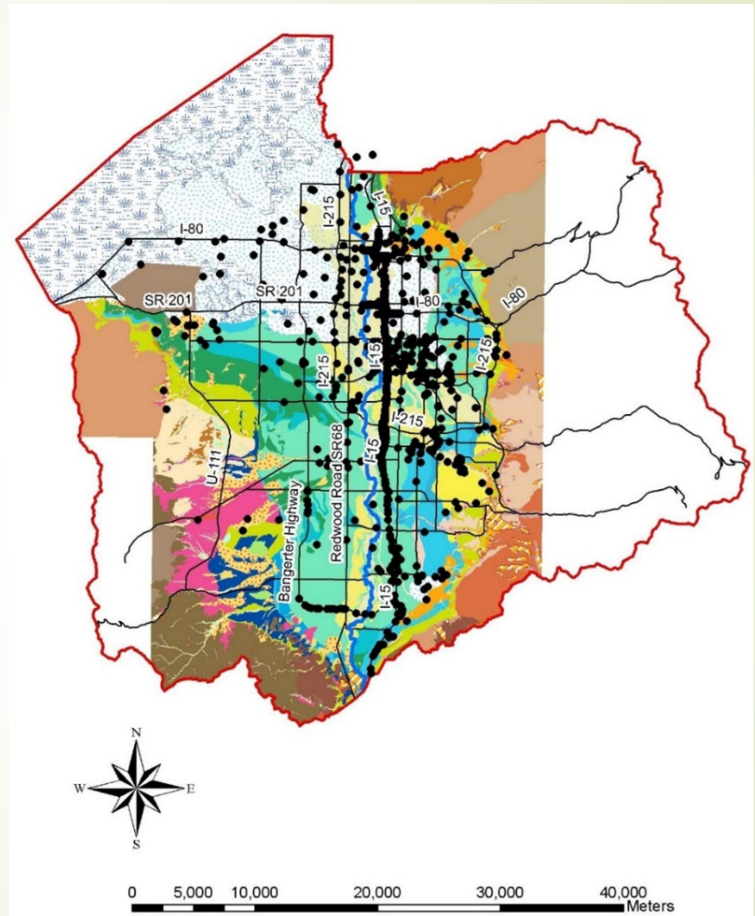


Estimates of peak ground acceleration
(Wong et al., 2002)

Estimation of Liquefaction Potential



Geologic Map



Geotechnical Boreholes

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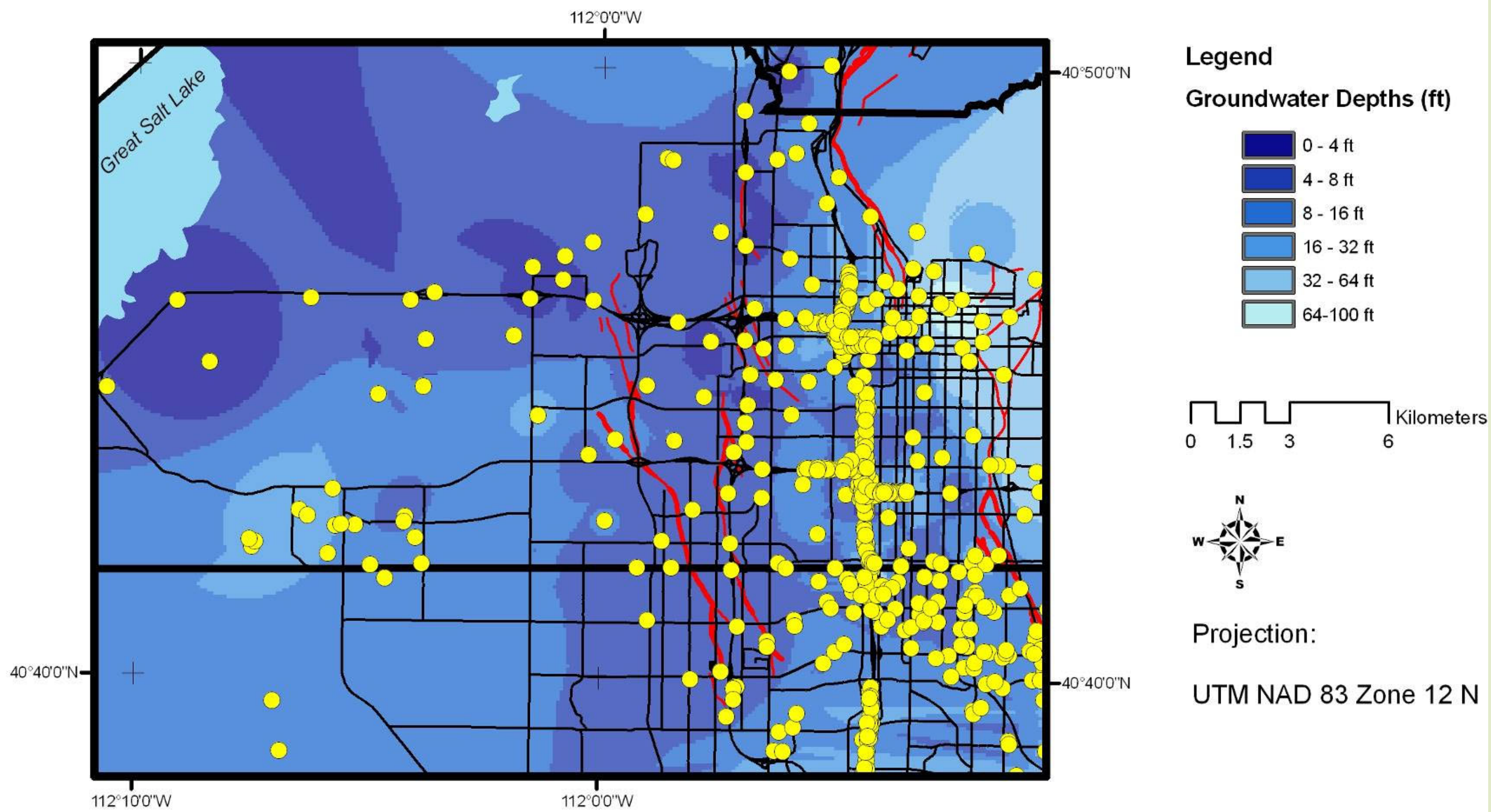
Estimation of Liquefaction Potential



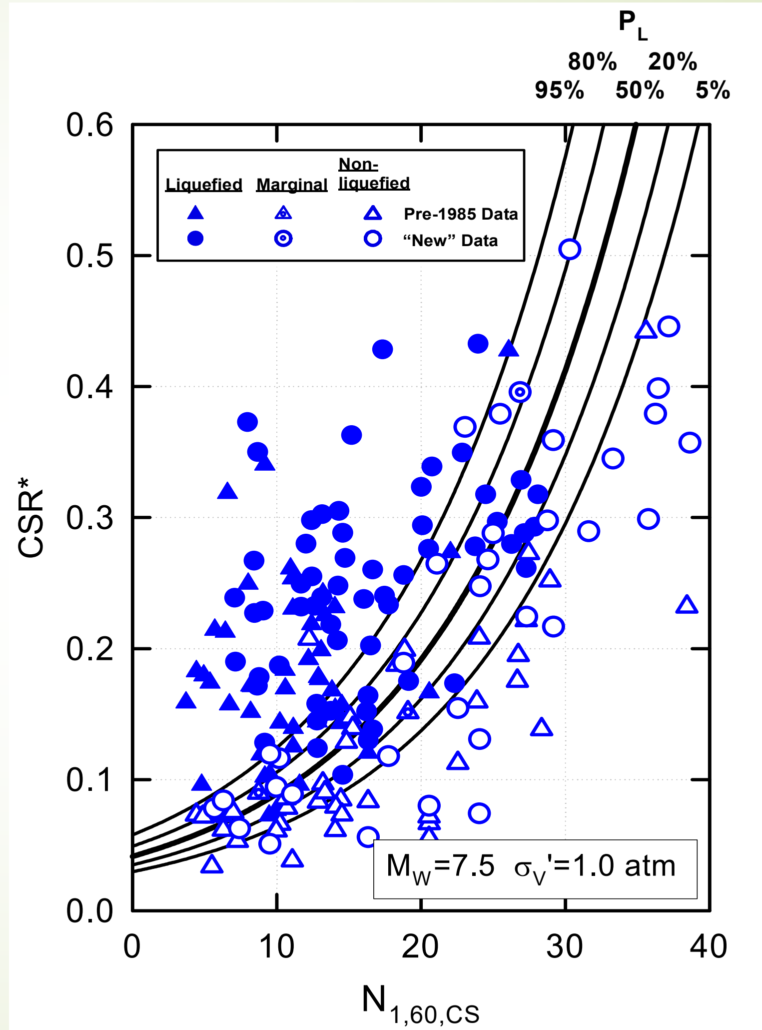
Groundwater Depth Map

Estimation of Liquefaction Potential

Recommended "Probabilistic" SPT-Based Liquefaction Triggering Correlation

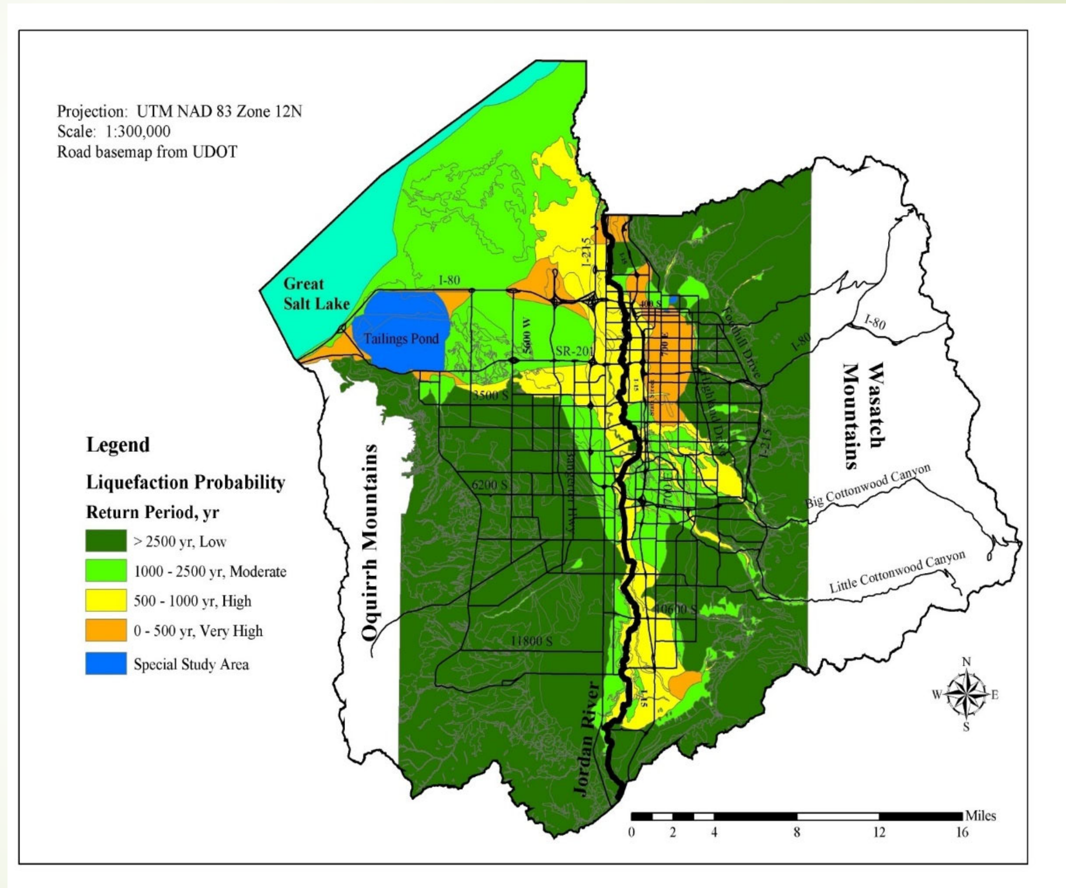
(For MW=7.5 and σv'=1.0 atm)

(Seed et al. 2003)



Liquefaction Potential Map

- Liquefaction Potential Maps
  - Combine liquefaction susceptibility (capacity) with seismic input (demand).
  - Demand can be expressed as a deterministic scenario event or a probabilistic-based estimate obtained from a probabilistic seismic hazard analysis (PSHA)



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Types of Liquefaction Maps

- Liquefaction Susceptibility Maps
- Liquefaction Potential Maps
- Ground Failure Maps

Estimation of Ground Displacement

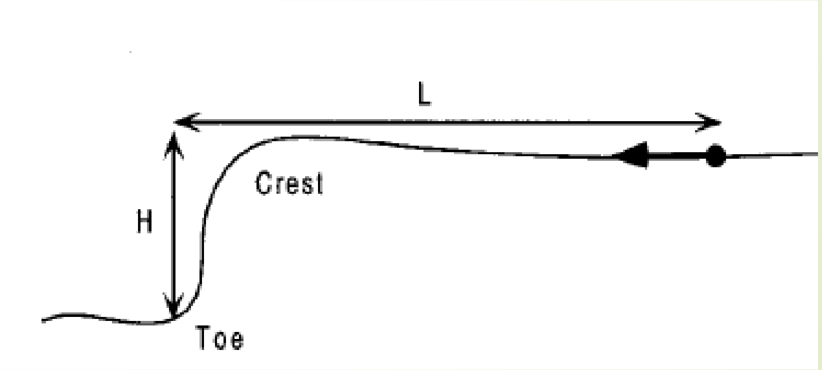
- P(DH > x) = Σ P[(DH > x) | L] P[L | A, M, R] P[A, M, R]
  where:
  - P(DH>x) = The probability of lateral spread exceeding a threshold value (e.g., x= 0.1 m and 0.3 m)
  - P[L | A,M,R] = the probability of liquefaction given an acceleration, magnitude, and source distance.
  - P[A,M,R] = joint probability density function of peak ground acceleration, magnitude and source distance.

Estimation of Ground Displacement

Bartlett and Youd (1995); Youd, Hansen, Bartlett (2002); Gillins and Bartlett (2014).

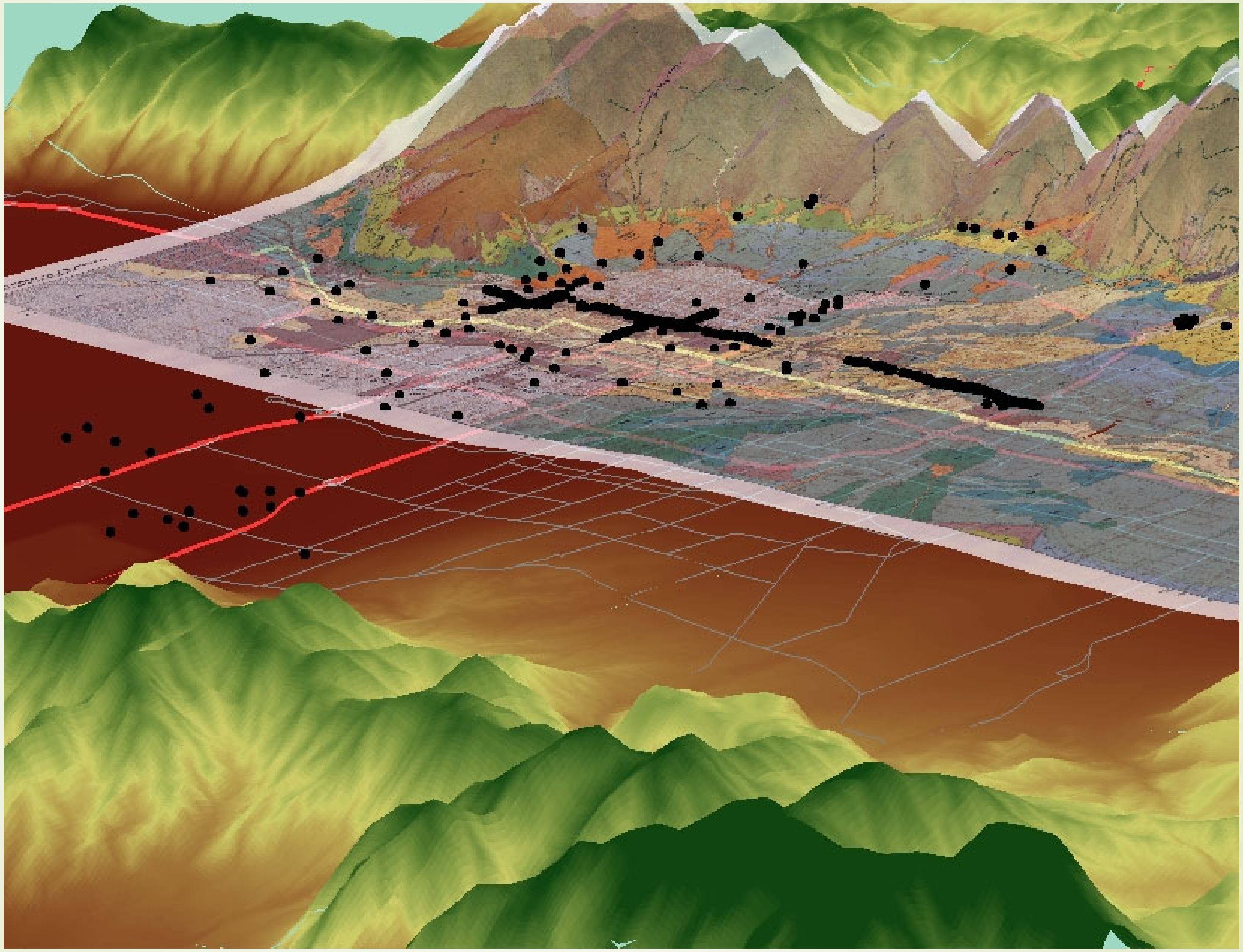
$$LogD_H = \begin{array}{c} b_o + b_{off}\alpha + b_1 M + b_2 LogR^* + b_3 R + b_4 LogW + b_5 LogS + b_6 LogT_{15} + \\ + b_7 Log(100 - F_{15}) + b_8 Log(D50_{15} + 0.1\text{ mm}) \end{array}$$

- Seismic Factors
  - *M, R*
- Topographic Factors
  - *W, S*
- Geotechnical Factors
  - T_{15}, F_{15}, $D50_{15}$



Free-face ratio: *W (%) = H / L * 100*

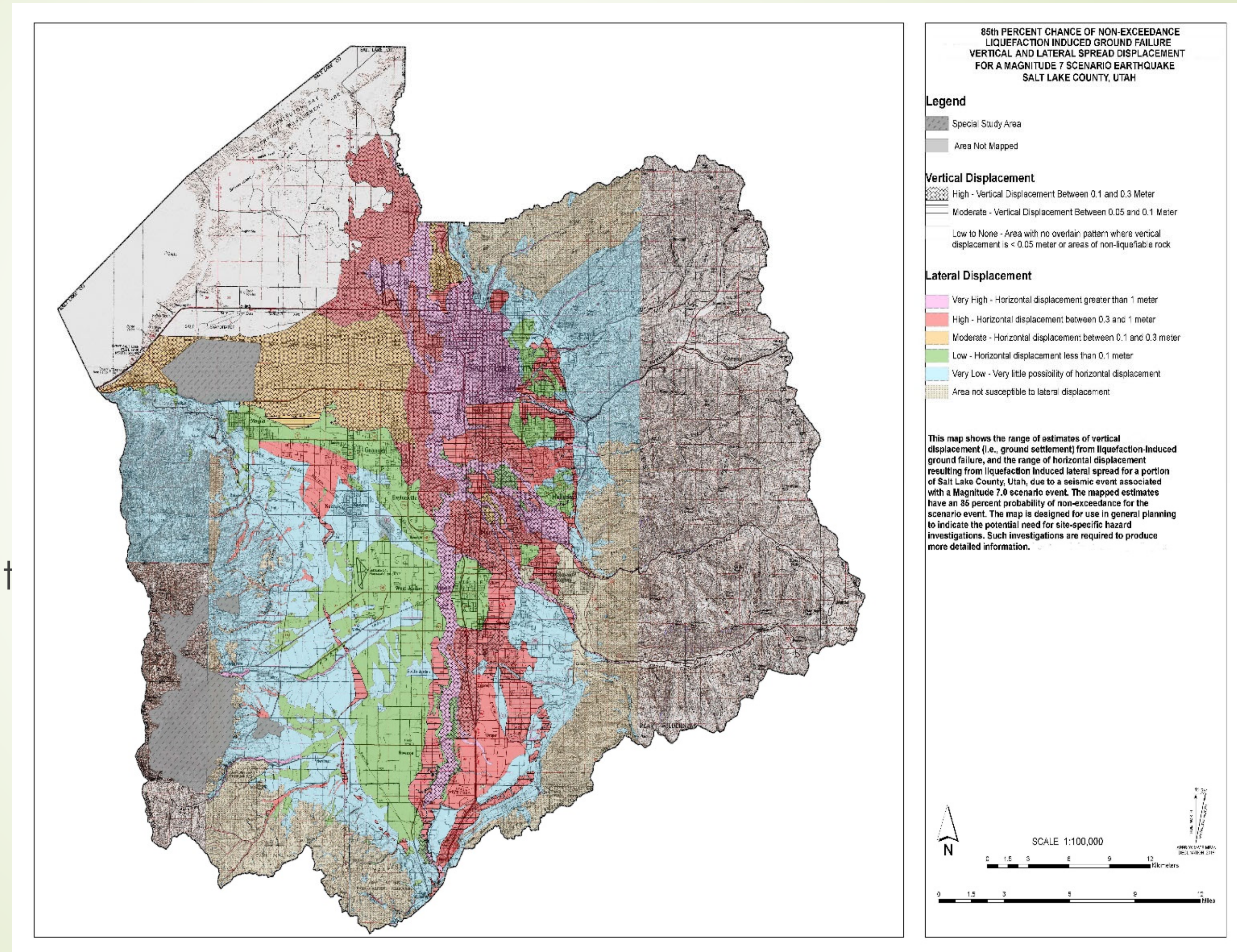
Estimation of Ground Displacement



Boreholes, Surficial Geology Map, Digital Elevation Model

Lateral Spread Ground Failure Map

- Ground Failure Maps
  - Consider liquefaction potential
  - Consider the amount of liquefaction displacement (e.g., lateral spread or ground settlement)



USGS science for a changing world

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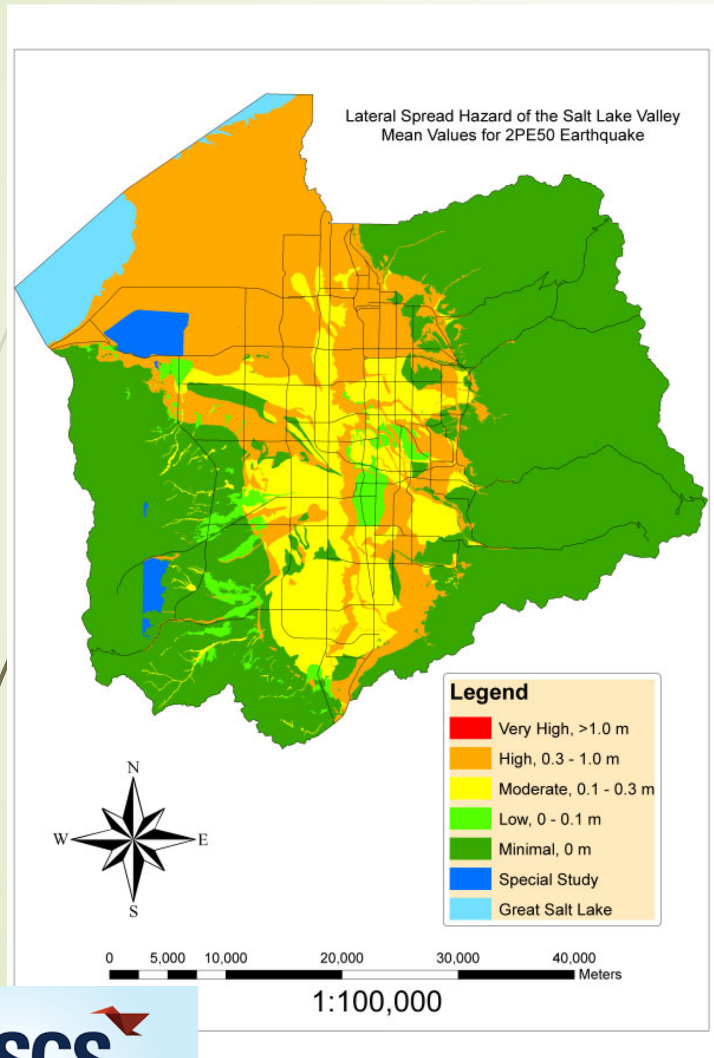
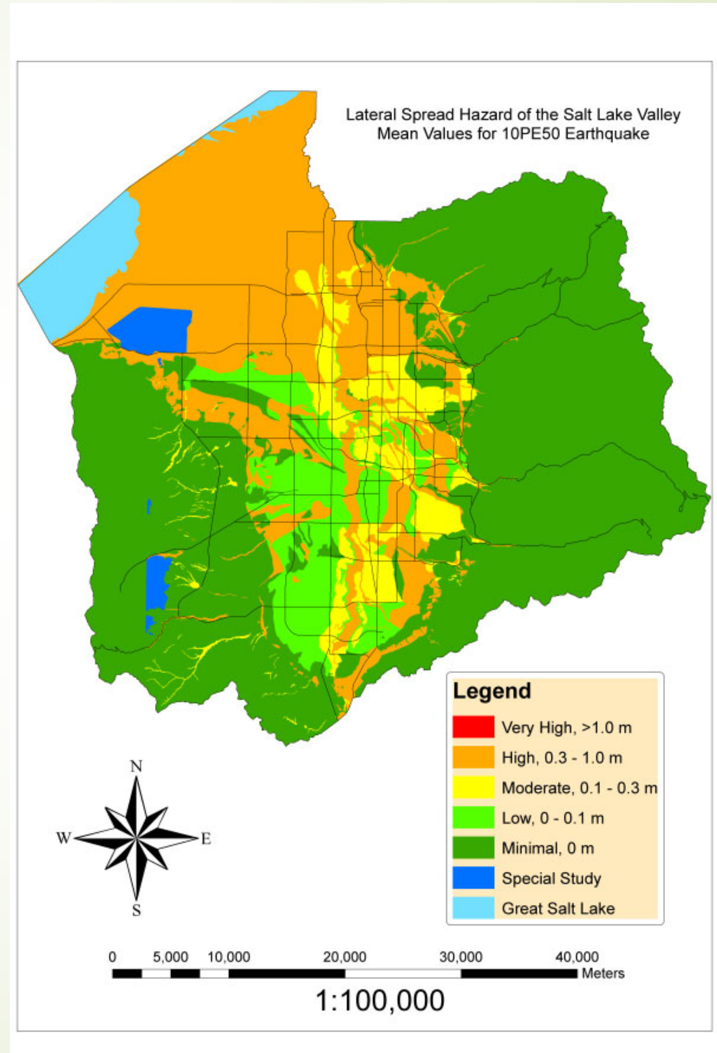
Maps 2500 and 500-year scenarios





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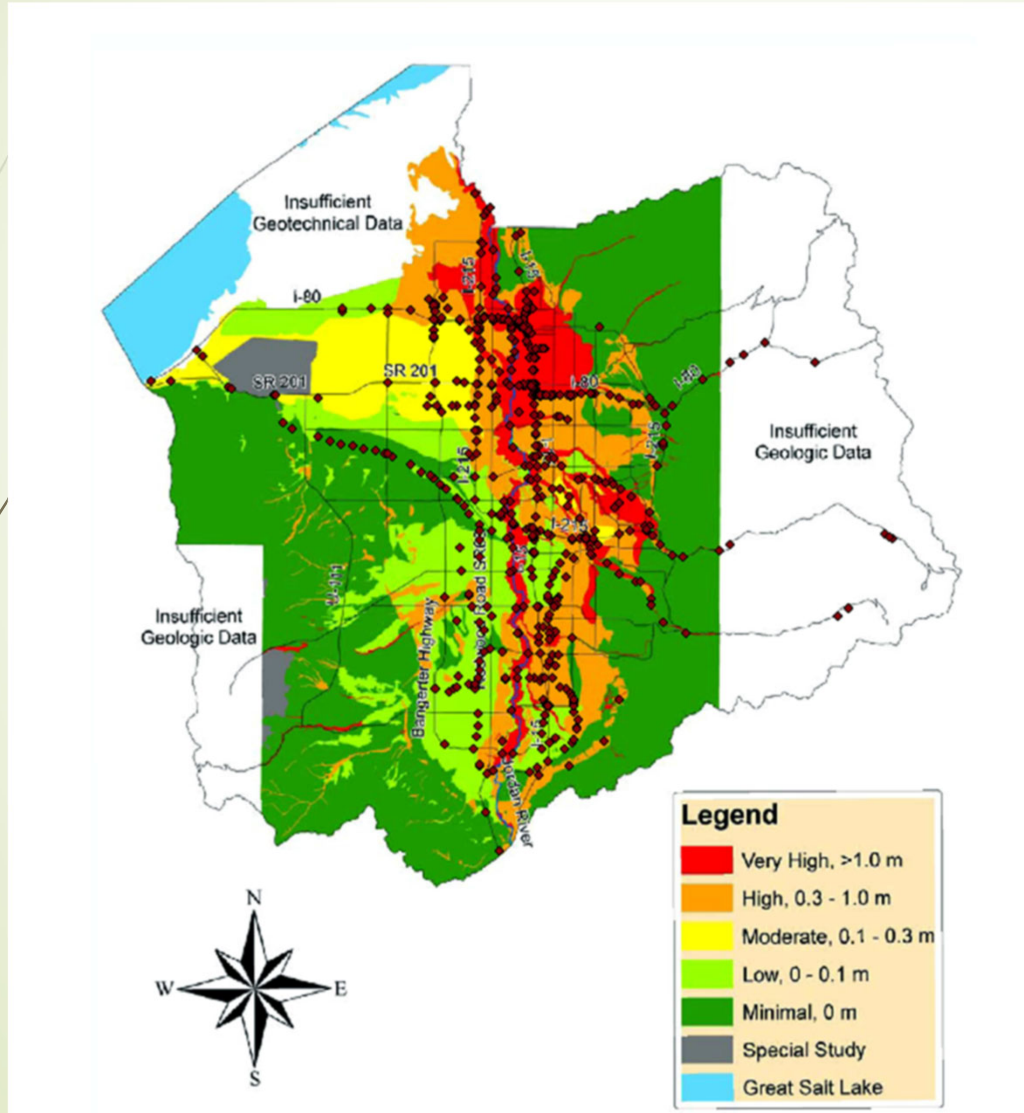
Bridge Locations, Salt Lake County



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Topics

- Liquefaction Effects
- Liquefaction Evaluations
- Liquefaction Research
- Liquefaction Maps
- **Liquefaction Hazard Assessment**
- Pipeline Protection
- Seismic Buffers
- Unreinforced Masonry (URM) Retrofitting

Bridge Fragility Curves

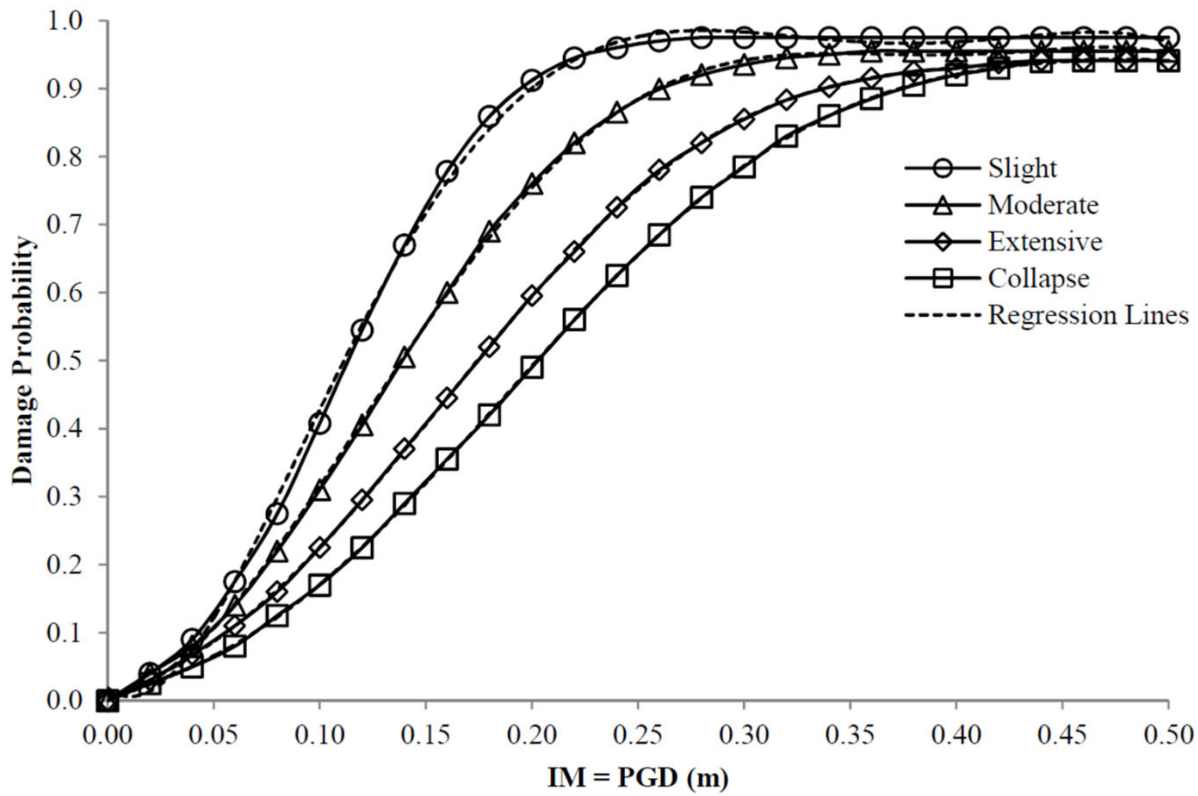


Figure 19: Polynomial fit fragility curves for continuous bridges with seat abutments (Brandenberg, Zhang, Kashighandi, Huo, & Zhao, 2011)

Vulnerable Bridges in Salt Lake Co.

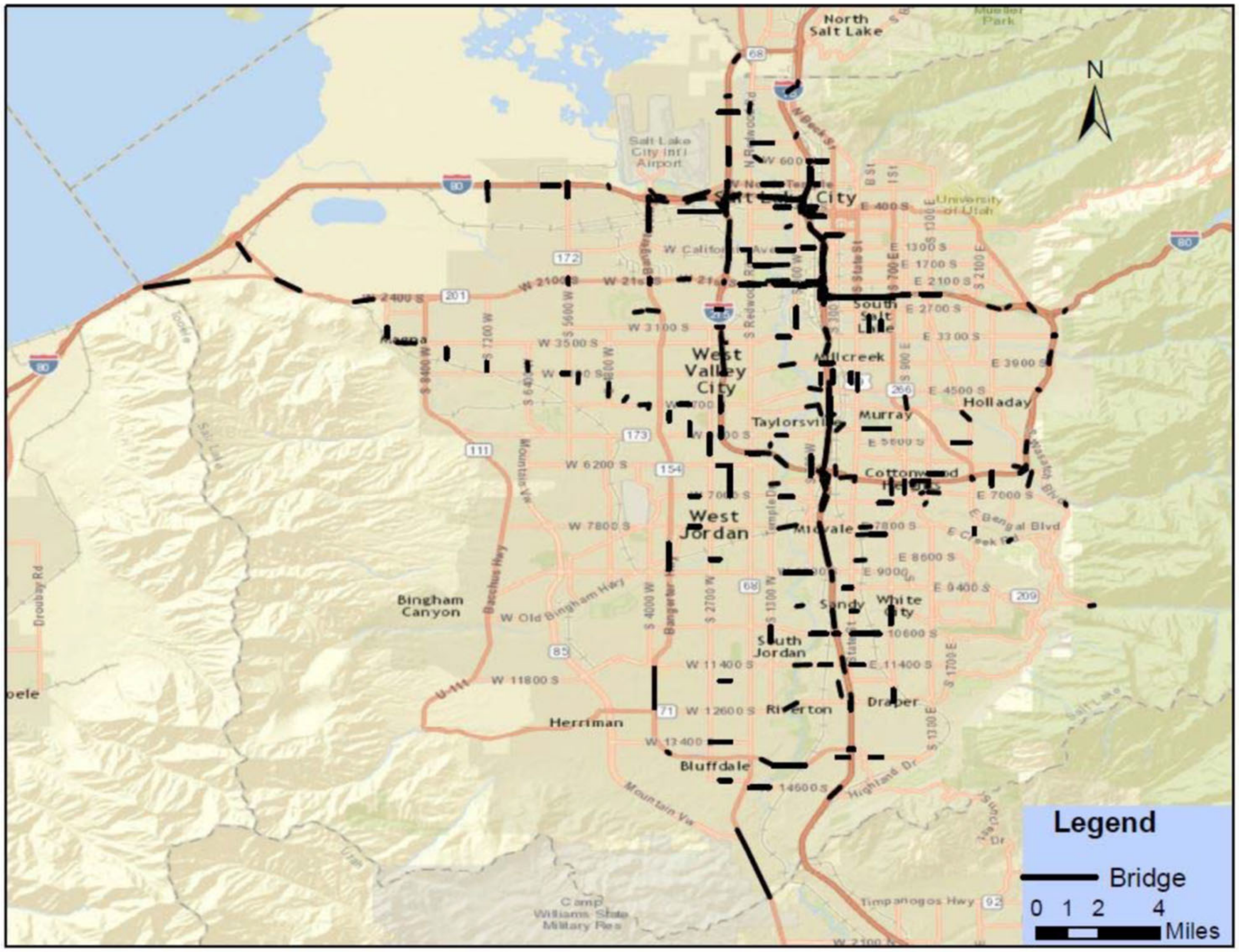
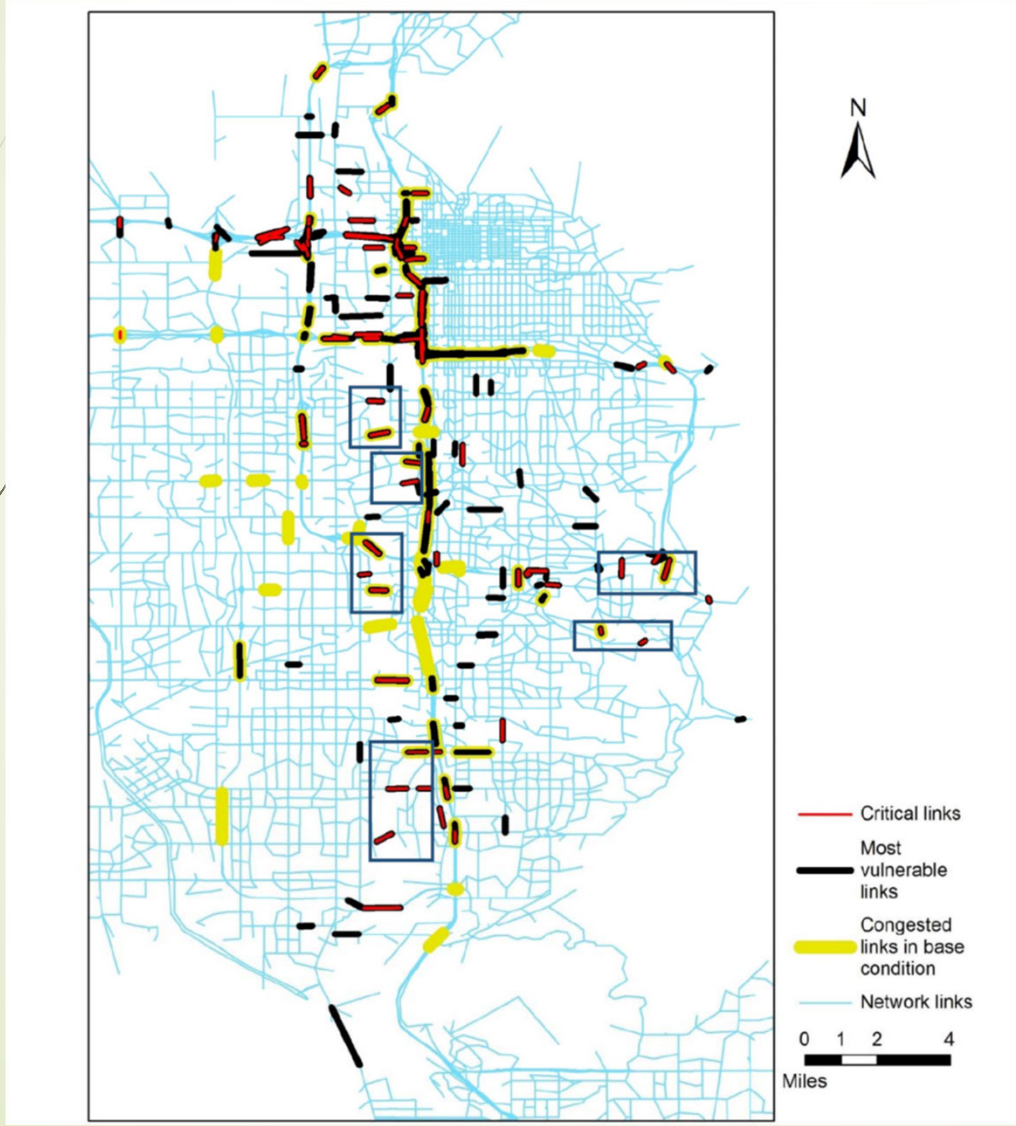


FIGURE 2 Vulnerable Links Located in Salt Lake County, Utah.

Prioritize Critical Bridges for Repair



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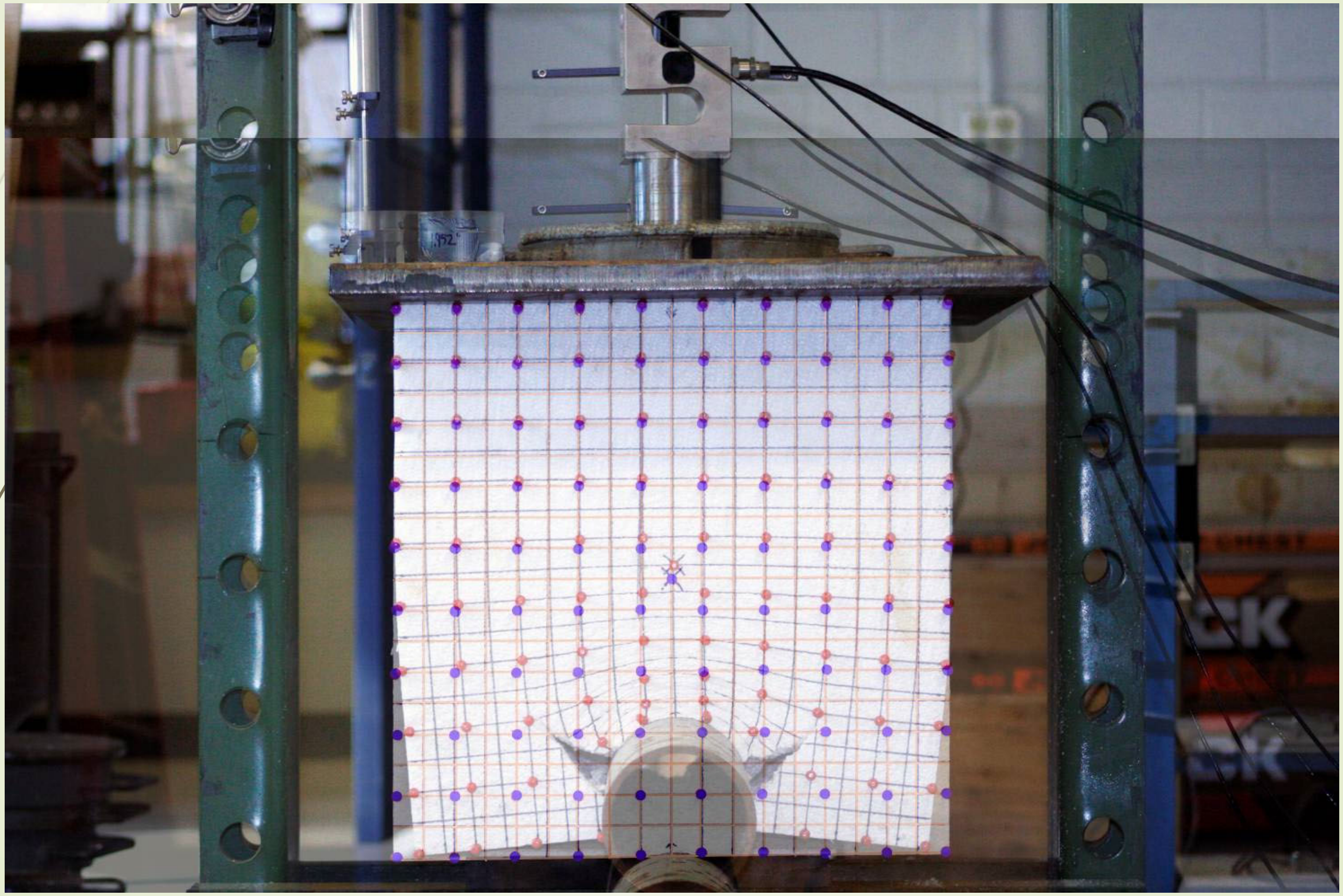
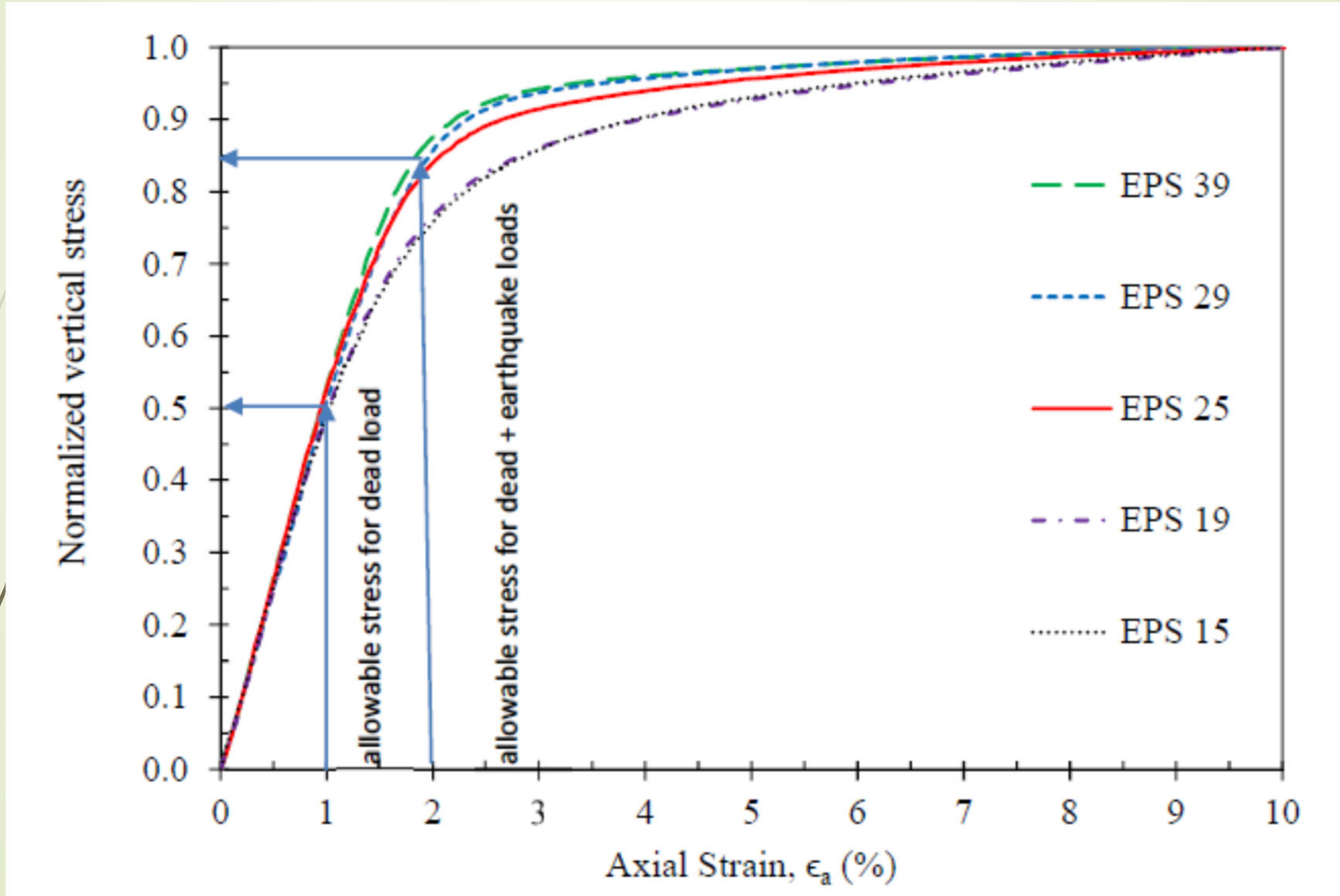
Slot Trench Cover System at Fault Crossing

Crossing of Wasatch Fault Zone in with High-Pressure Gas Line
Salt Lake City, Utah, Questar Gas Corp.

Geofoam - Pipe Interaction



Geofoam Stress – Strain Curves



Geofoam Test Results - Cycling

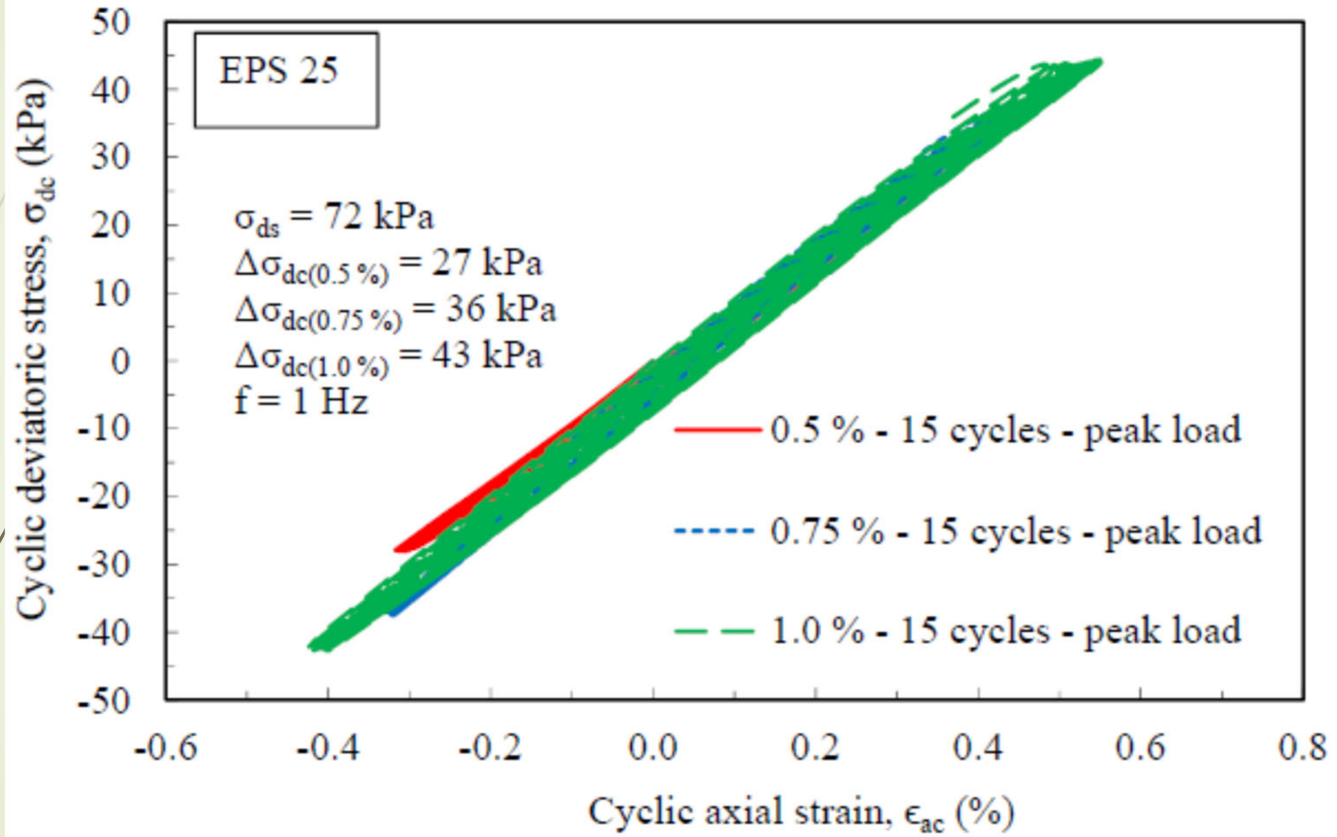


Figure 2-18 Results of cyclic uniaxial tests on three samples at three different level of cyclic deviatoric stresses under peak load with 15 number of cycles on EPS 25

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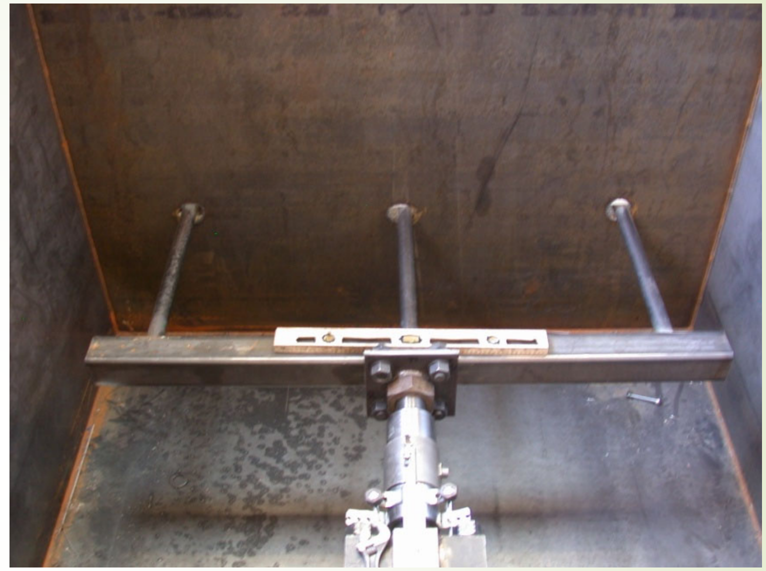
Geofoam – Pipe Testing Facility



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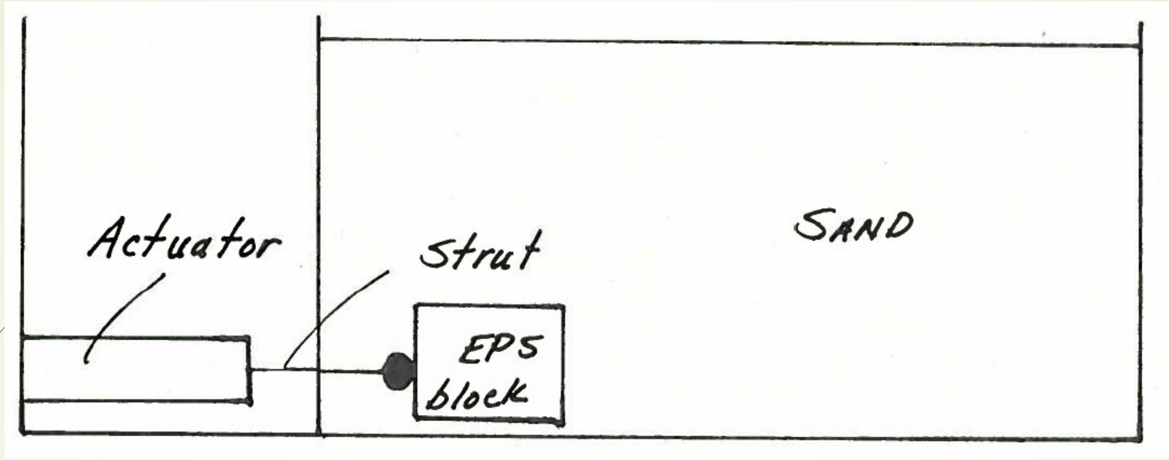
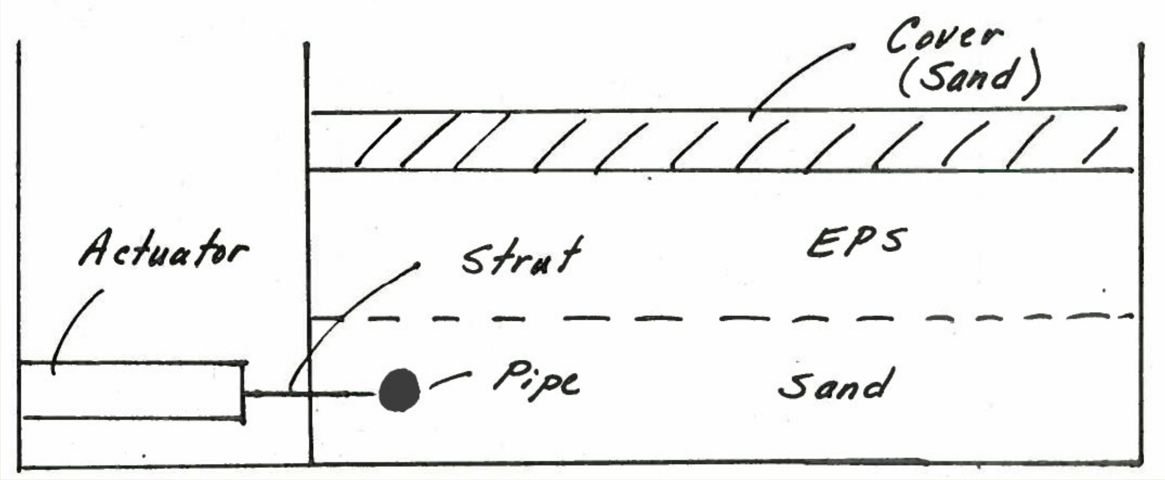
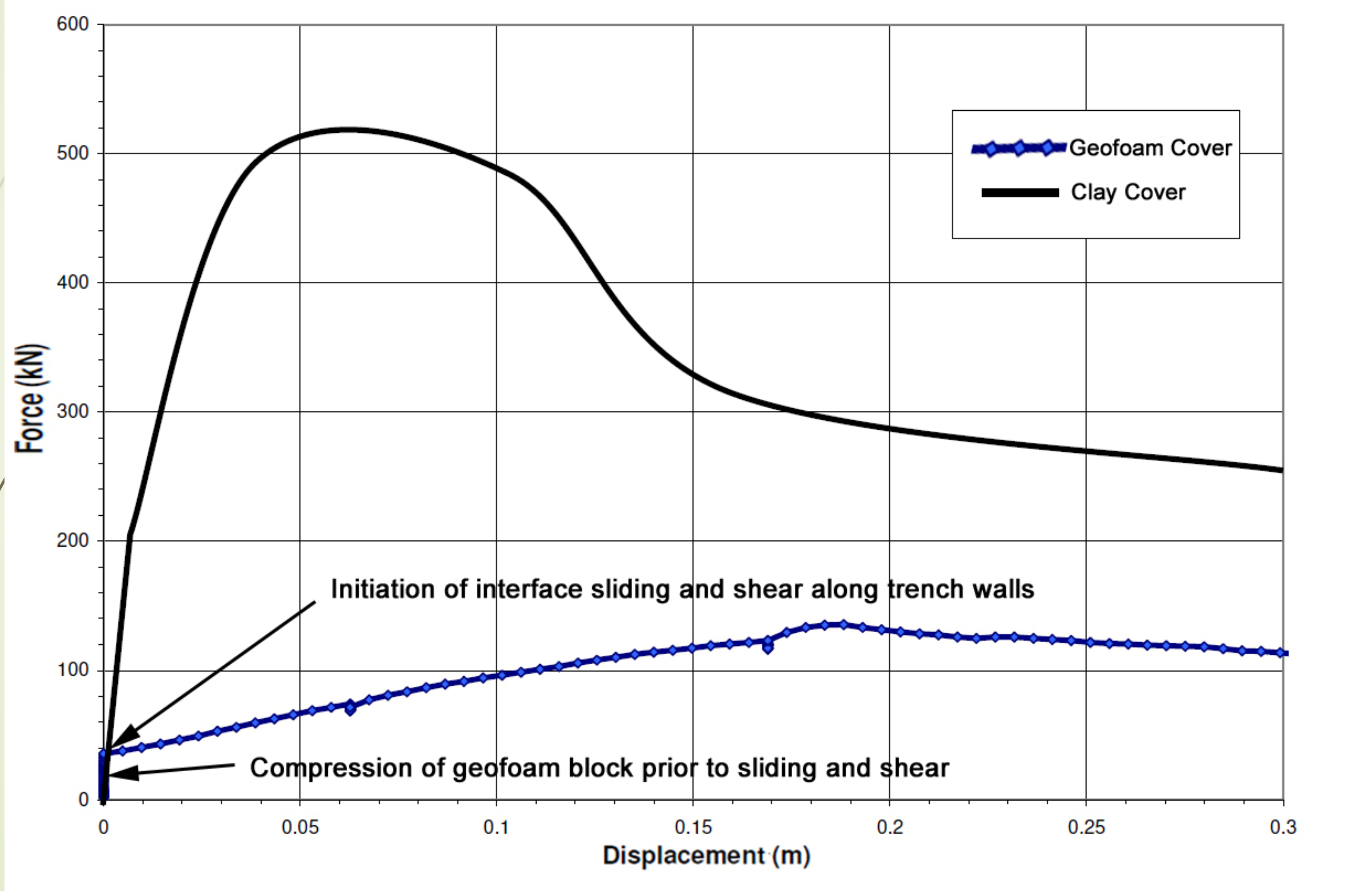
Sketch of Geofoam – Pipe Test Facility





Geofoam-Pipe Uplift Field Tests

Force-Displacement from Uplift Tests



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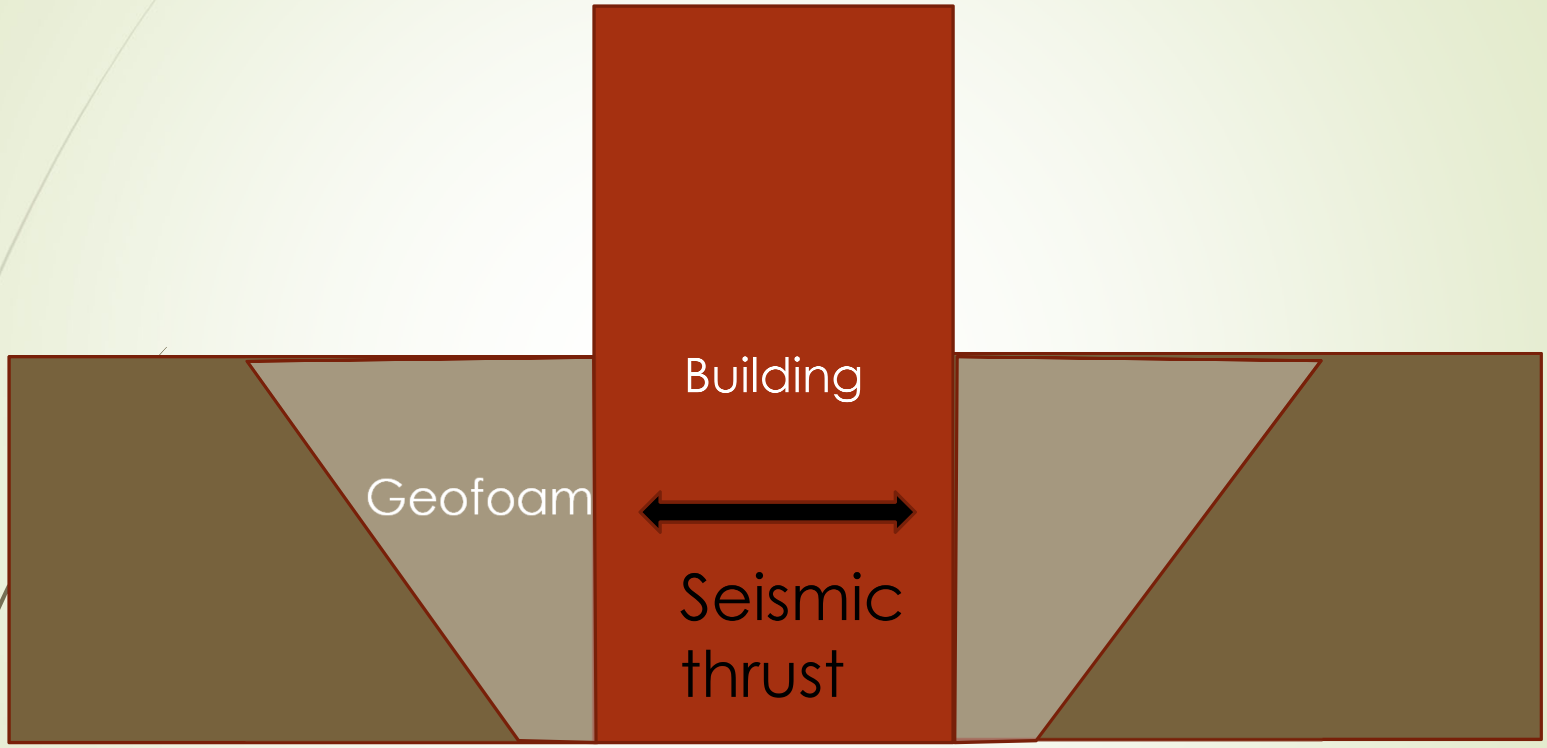
- Unreinforced Masonry (URM) Retrofitting

Geofoam for Seismic Buffers



Seismic thrust greatly reduced due to low unit weight (mass) and compressibility of Geofoam

Geofoam – Seismic Buffers

Federal Courthouse – Salt Lake City

IHC Hospital – Murray, Ut

Casino/Hotel – Reidoso, NM

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Unreinforced Masonry Collapse

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Unreinforced Masonry Collapse

Human Impact

Casualties

Life Threatening Injuries	7,400 - 9,300
Fatalities	2,000 - 2,500

Building Damage

Damage Category	Number of Buildings Affected	Percent of 757,000 Total Buildings
Slight	125,500	16.58%
Moderate	78,400	10.36%
Extensive	48,800	6.45%
Complete	55,400	7.32%

The scenario shows that 90,200 URM buildings—over 61 percent of the total number in the 12-county area—will be moderately damaged or totally destroyed following a magnitude 7.0 earthquake. Many

Economic Impact

Estimated Short-Term Economic Loss

Building-Related	$24.9 billion
Income	$6.9 billion
Lifeline-Related	$1.4 billion
Total	$33.2 billion

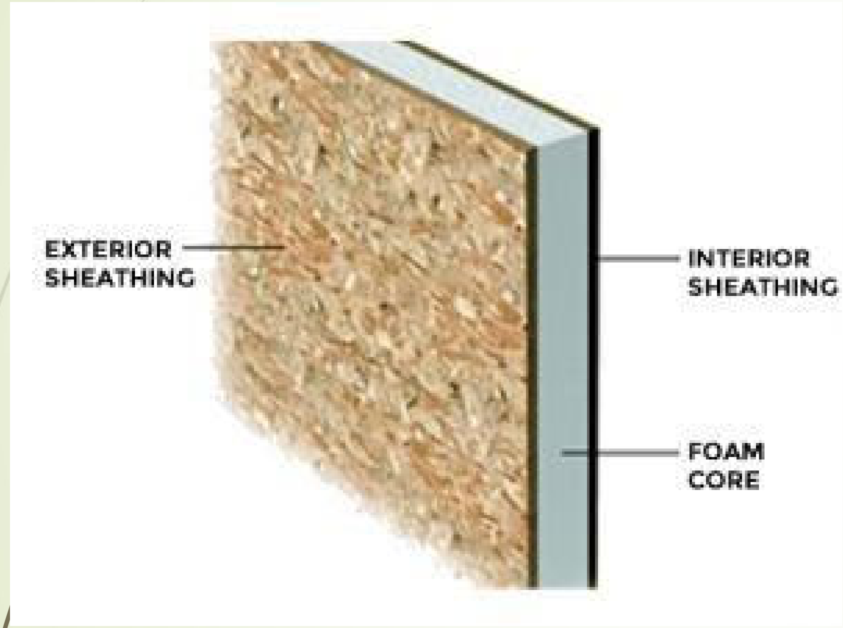
Scenario for a Magnitude 7.0 Earthquake on the Wasatch Fault–Salt Lake City Segment

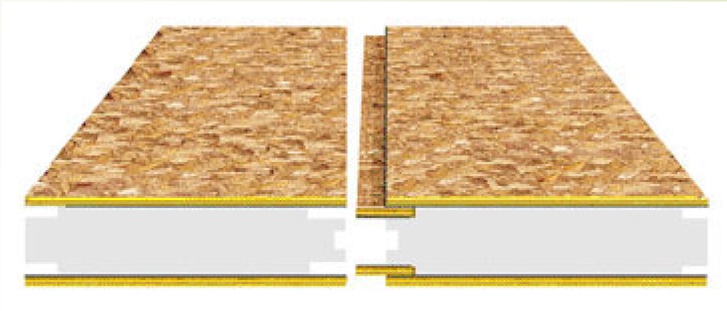
Hazards and Loss Estimates

EERI

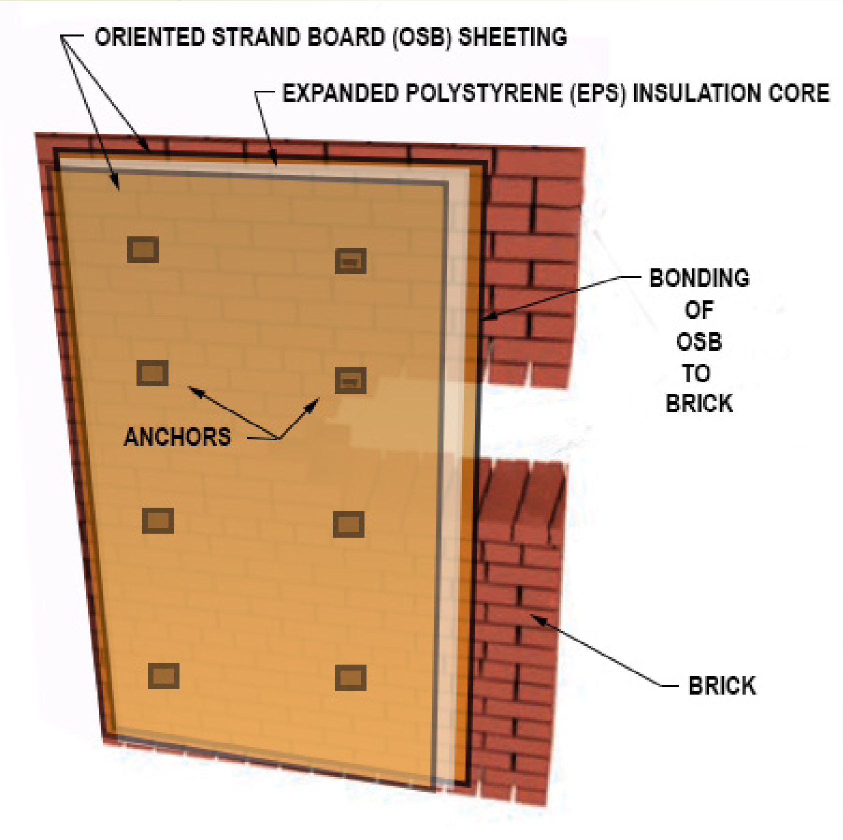
June 4, 2015

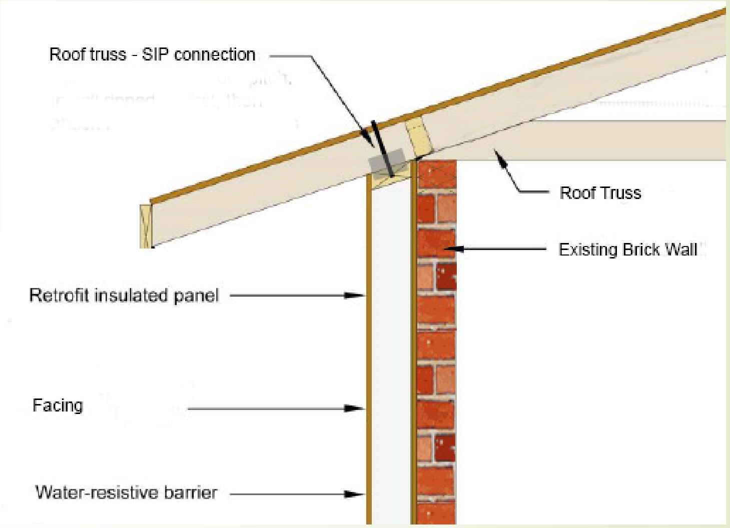
Structural Insulated Panels (SIPs)

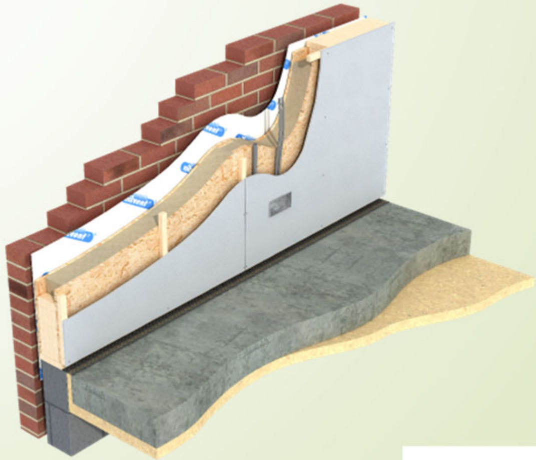




SIP Retrofitting of Brick







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University of Utah Asia Campus

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University of Utah Salt Lake Campus

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http://www.civil.utah.edu/~bartlett/pubs/