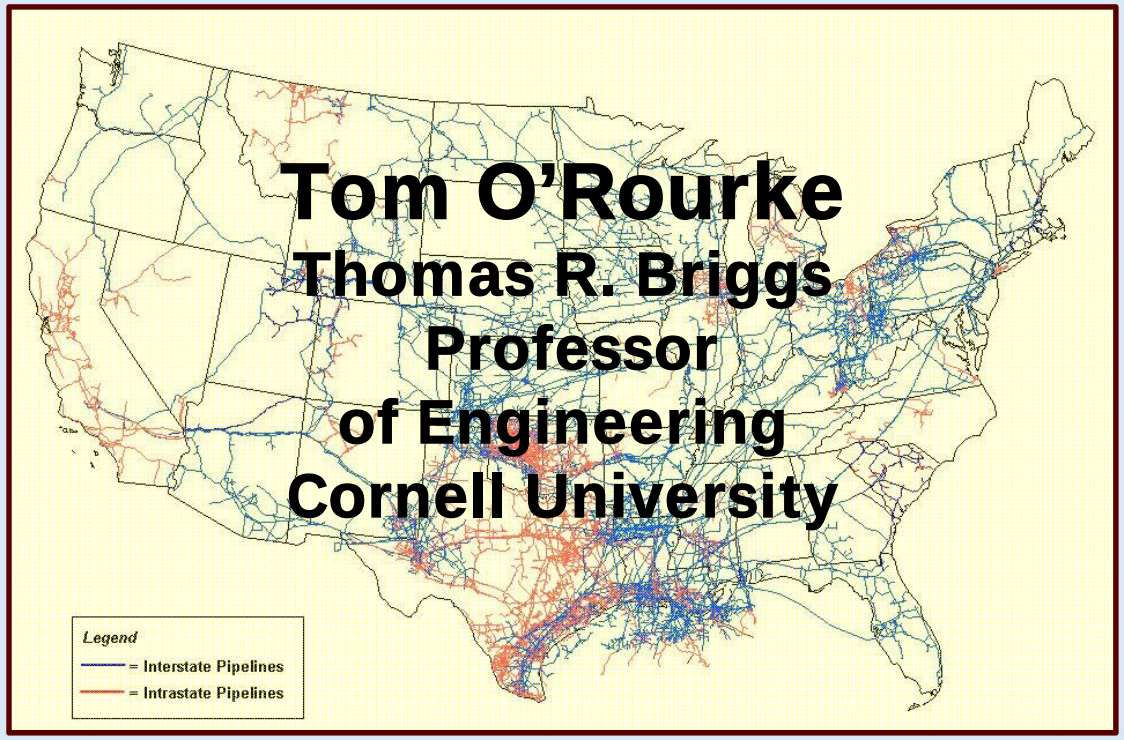
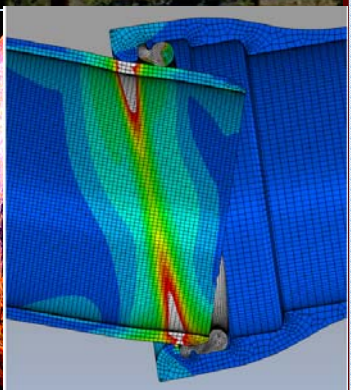
LIQUEFACTION-INDUCED LATERAL SPREADING & ITS EFFECTS ON STRUCTURES & LIFELINES



Tom O'Rourke
Thomas R. Briggs
Professor
of Engineering
Cornell University



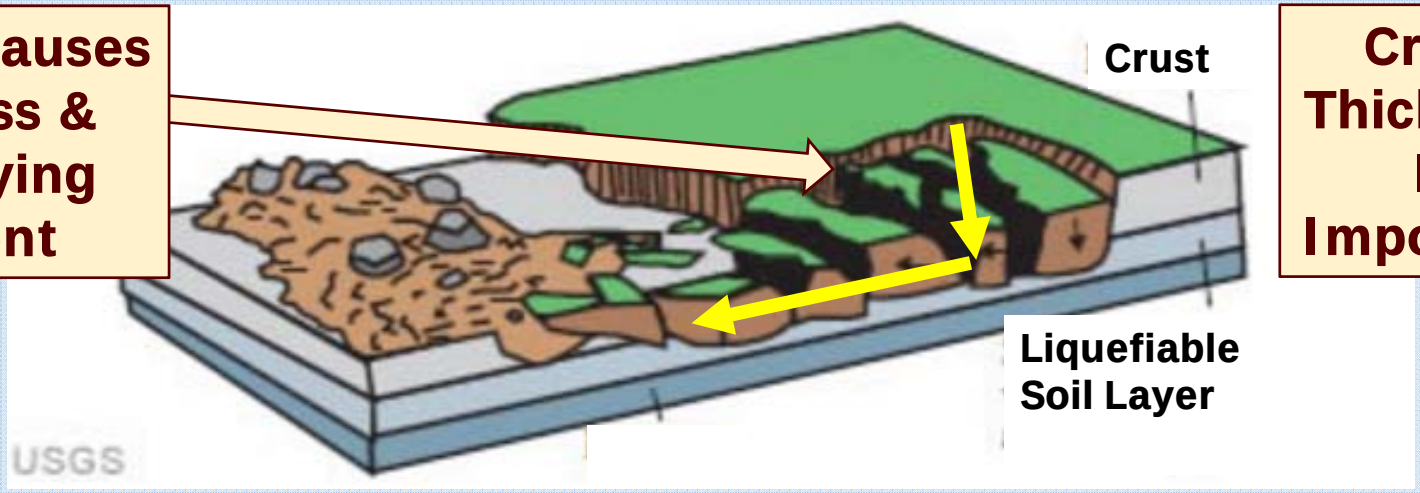
TOPICS

- Ground Movements
- Geologic Controls
- Soil/Pipeline Interaction
- Next Generation Pipelines
- Pipeline System Performance
- Best Path Forward

COUPLED LATERAL AND VERTICAL GROUND DEFORMATION

- Liquefcation-induced lateral soil movement is generally accompanied by vertical movement
- Need to identify & quantify coupling mechanisms between lateral and vertical movement.

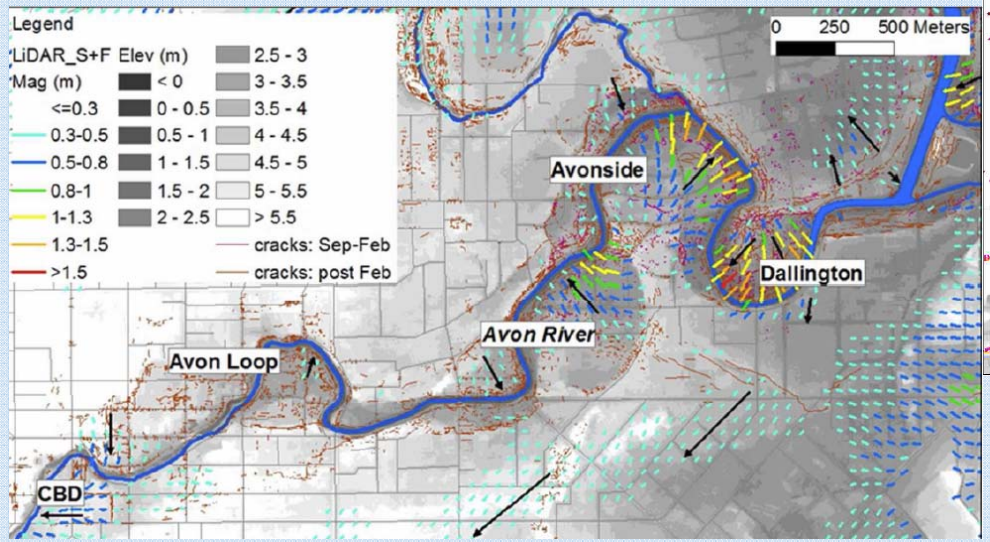
Soil Ejecta Causes Volume Loss & Accompanying Settlement

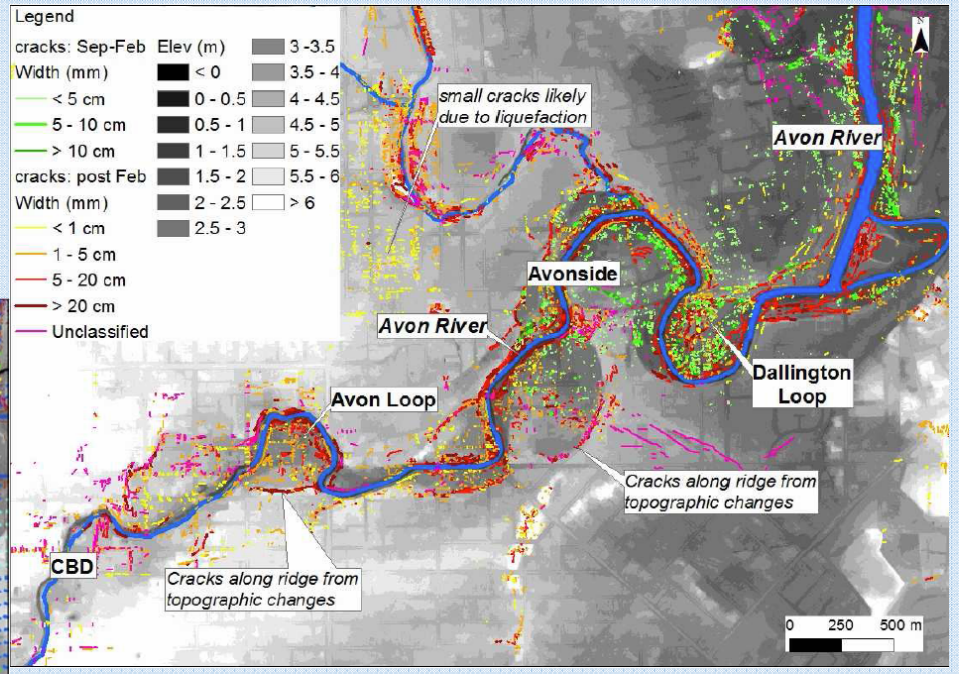


Crust Thickness Is Important

GEOLOGIC CONTROLS ON LIQUEFACTION-INDUCED GROUND DEFORMATION

- Geomorphology
- Stratigraphy
- Topography

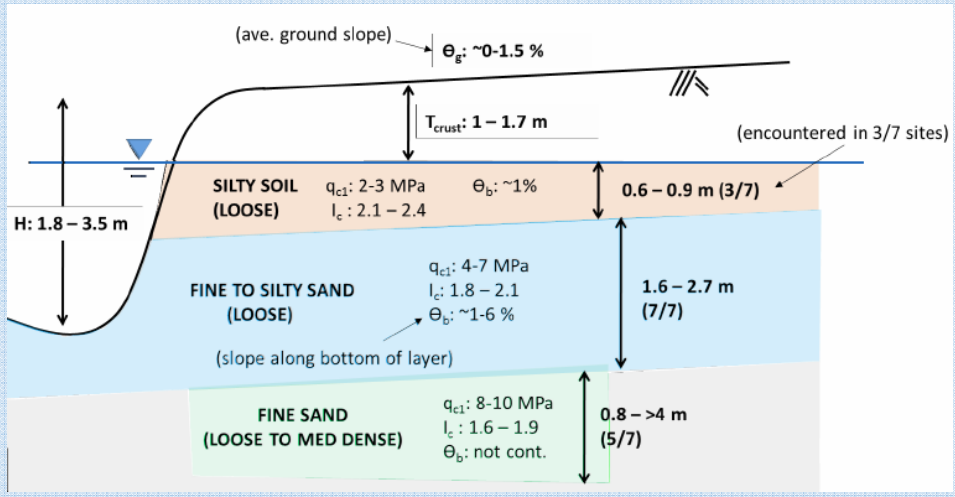




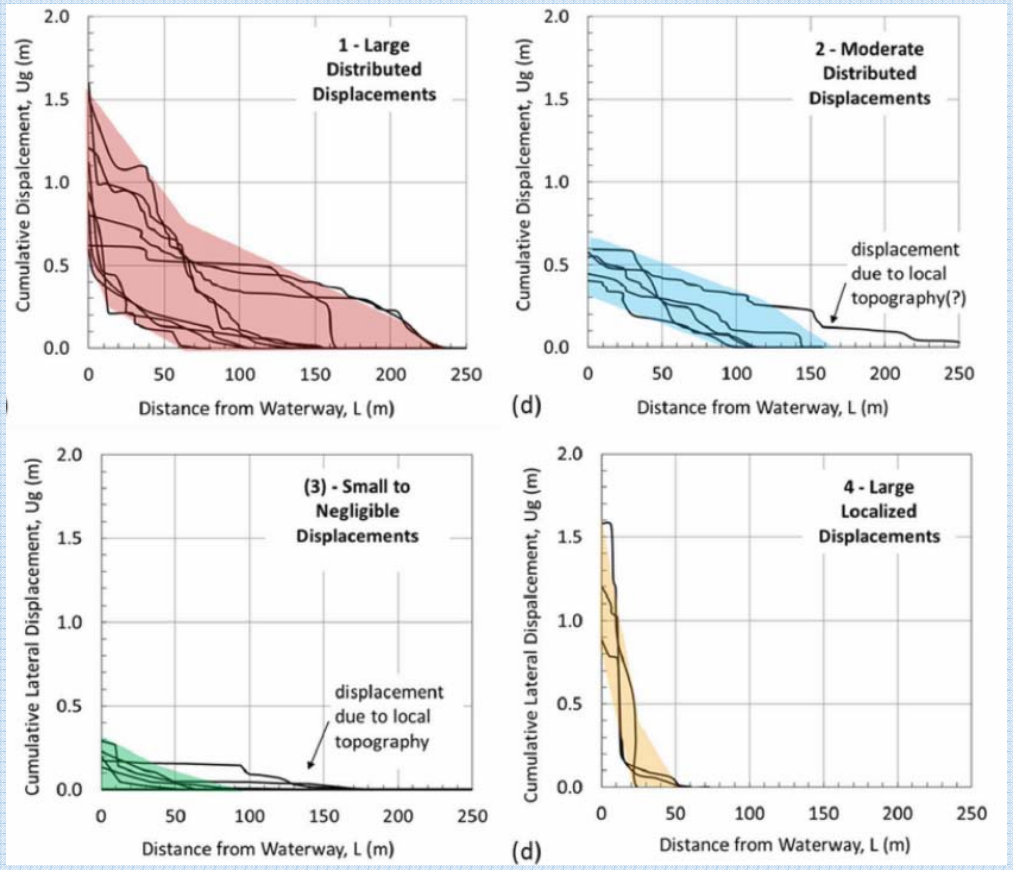
(Cubrinovski & Robinson, 2015)

GEOLOGIC CONTROLS ON LIQUEFACTION-INDUCED GROUND DEFORMATION

Stratigraphy

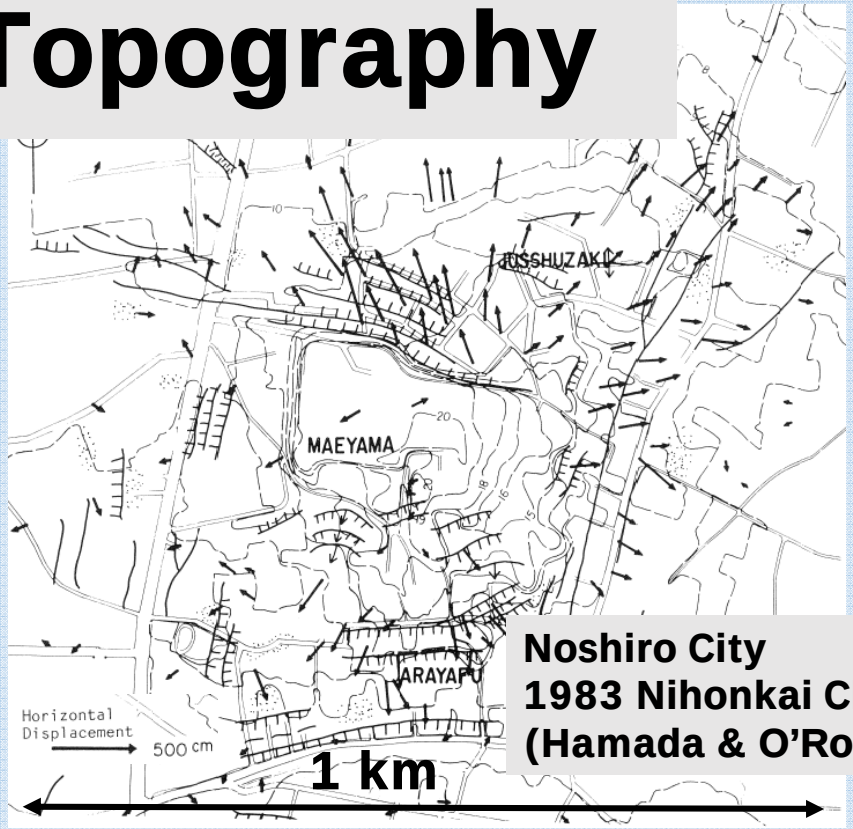


(Cubrinovski & Robinson, 2015)

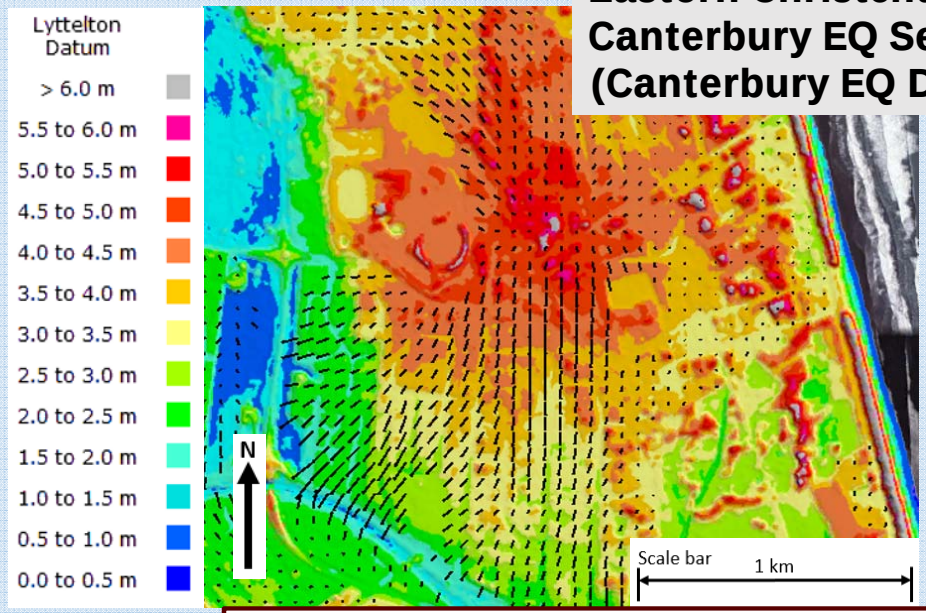


GEOLOGIC CONTROLS ON LIQUEFACTION-INDUCED GROUND DEFORMATION

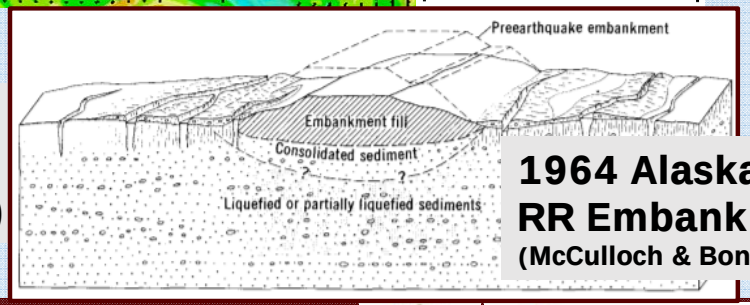
Topography



Noshiro City
1983 Nihonkai Chubu EQ
(Hamada & O'Rourke, 1992)

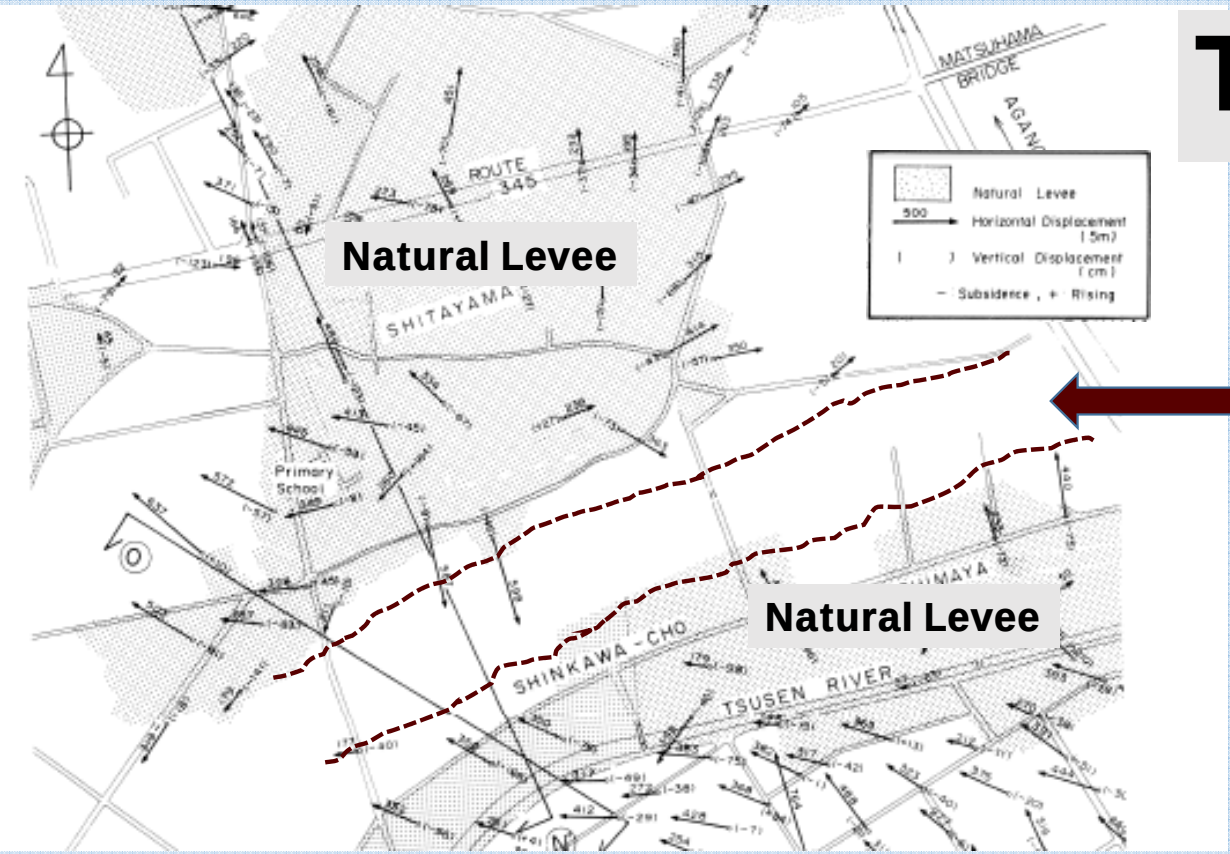


Eastern Christchurch
Canterbury EQ Sequence
(Canterbury EQ Database)



1964 Alaska EQ
RR Embankments
(McCulloch & Bonilla, 1978)

GEOLOGIC CONTROLS ON LIQUEFACTION-INDUCED GROUND DEFORMATION

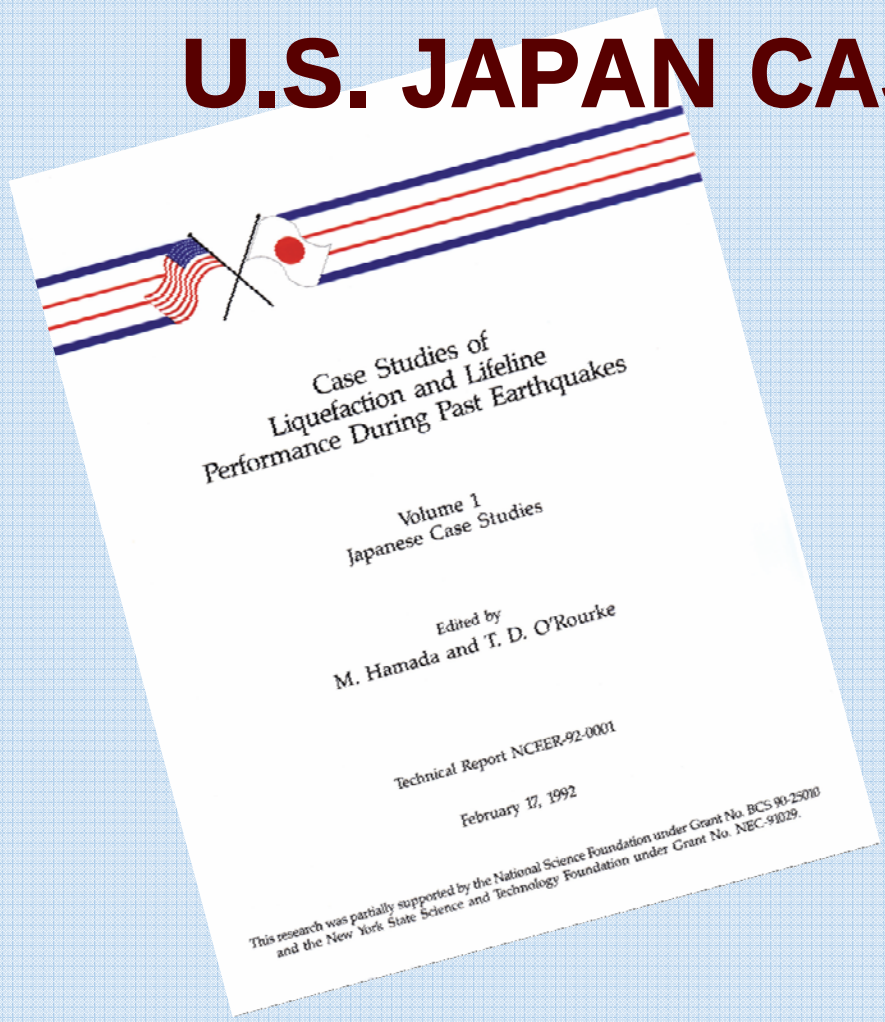


Topography

Previous Course of the Agano River

1964 Niigata EQ (Hamada & O'Rourke, 1992)

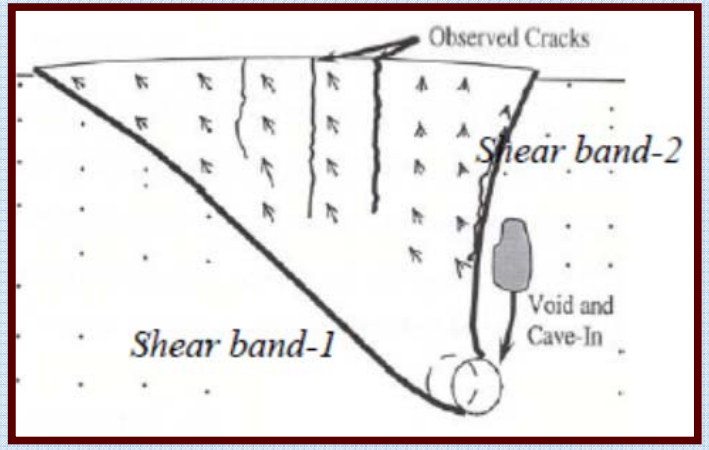
U.S. JAPAN CASE HISTORIES



EXTREME SOIL-PIPELINE INTERACTION

- Earthquakes
- Hurricanes and Floods
- Landslides: Aerial and Submarine
- Tunneling and Deep Excavations
- Subsidence

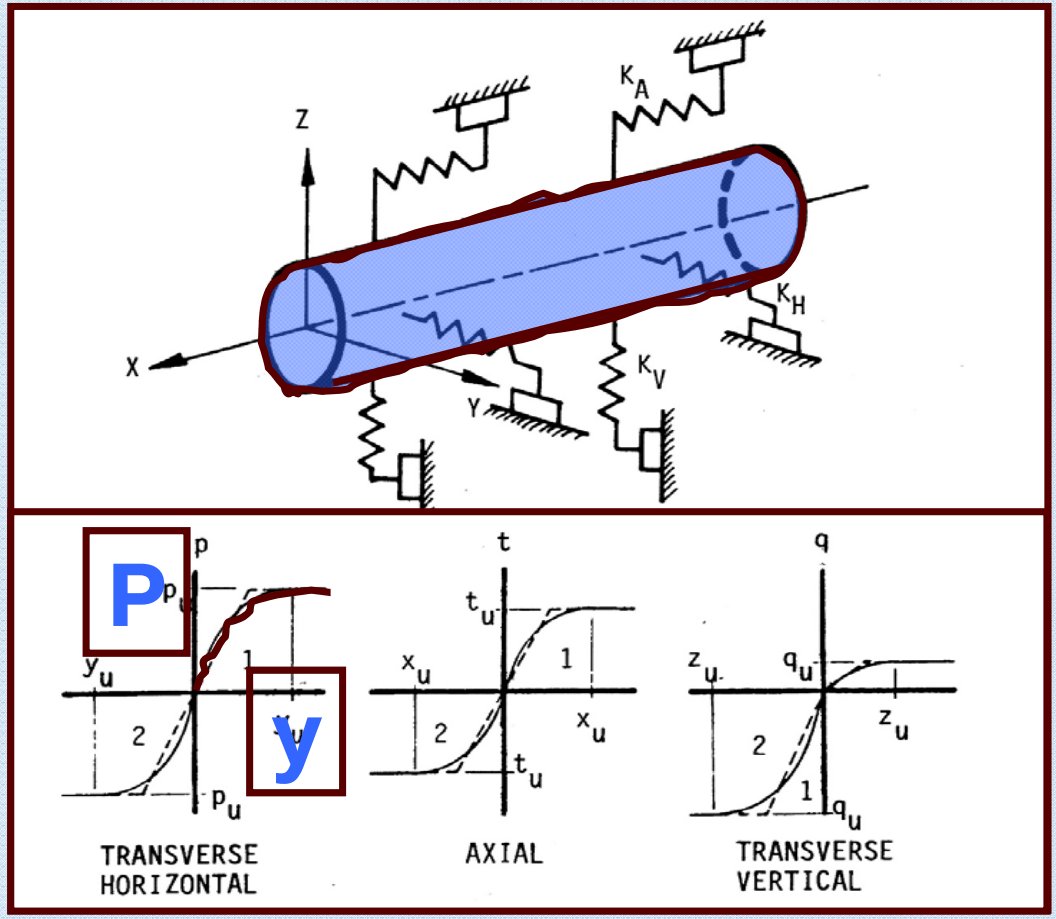
Soil Material & Geometric Nonlinearities



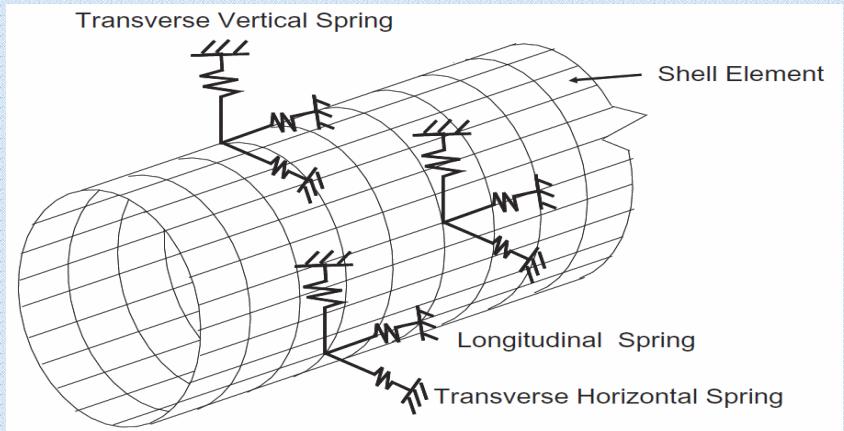
Pipeline Material & Geometric Nonlinearities

SOIL-PIPELINE INTERACTION

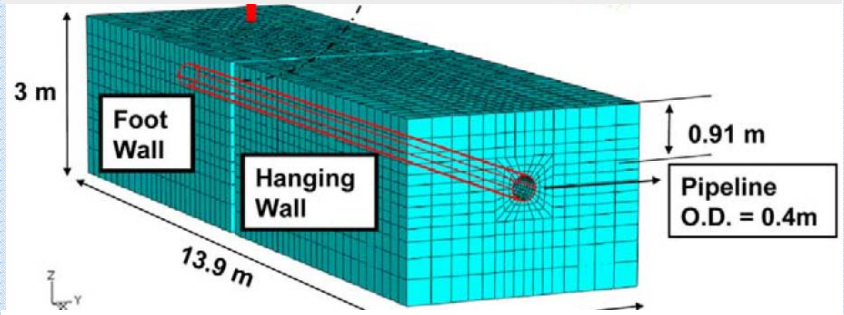
- Nonlinear Interaction Relationships Calibrated by Full-Scale Experiments
- Can Replicate Complex Interactions in Pipe & Soil
- 3-D Continuum Modeling Evolving; Still Challenges



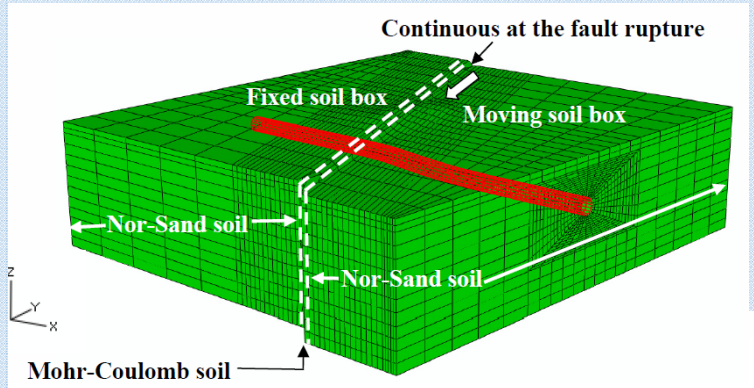
SOIL-PIPELINE INTERACTION MODELS



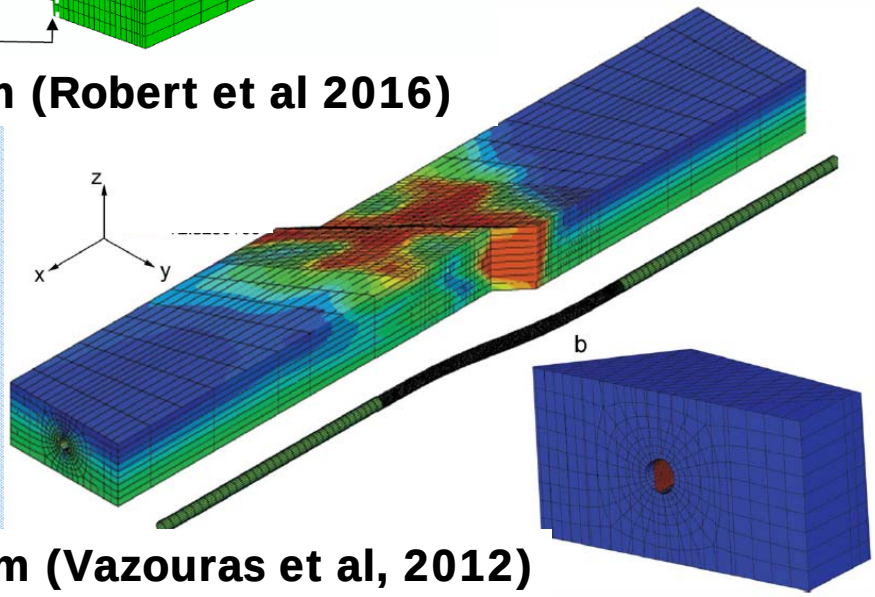
Shell & Discrete Soil Reactions (Xie et al 2013)



Continuum (Xie et al 2013)

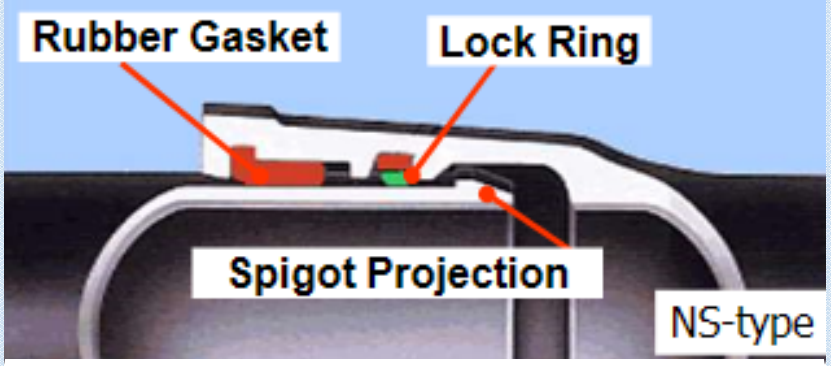


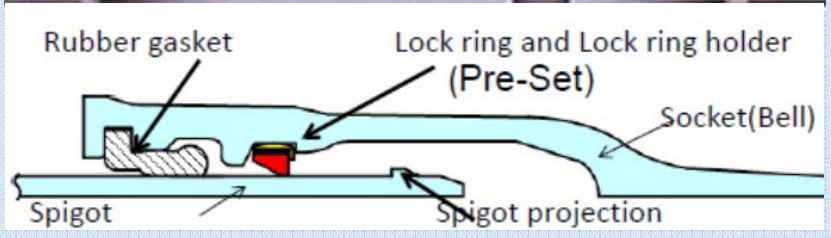
Continuum (Robert et al 2016)



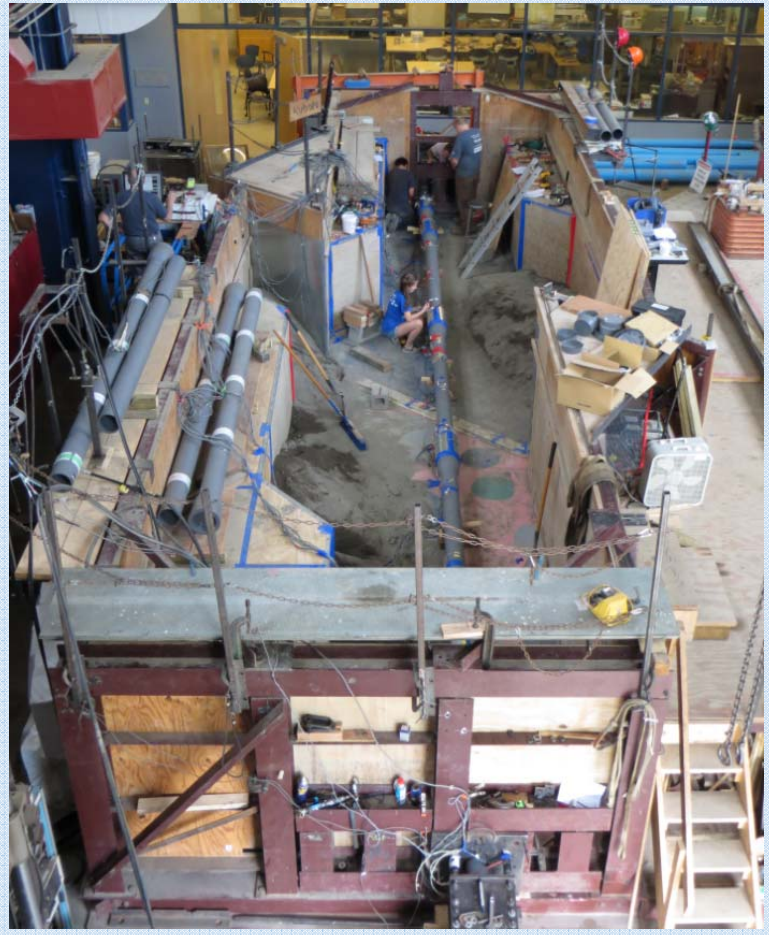
Continuum (Vazouras et al, 2012)

NEXT GENERATION HAZARD-RESILIENT PIPELINES

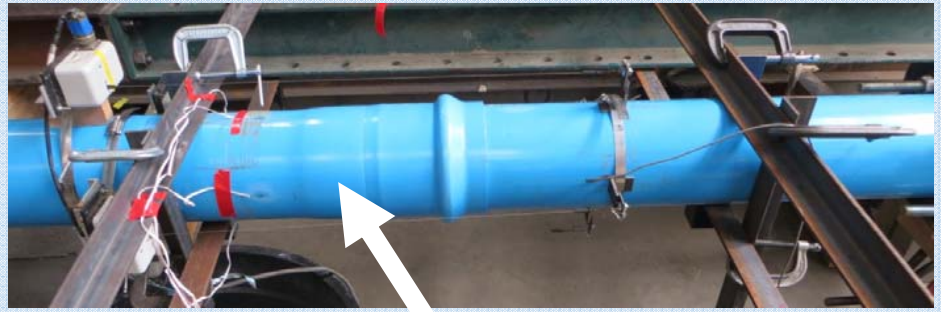




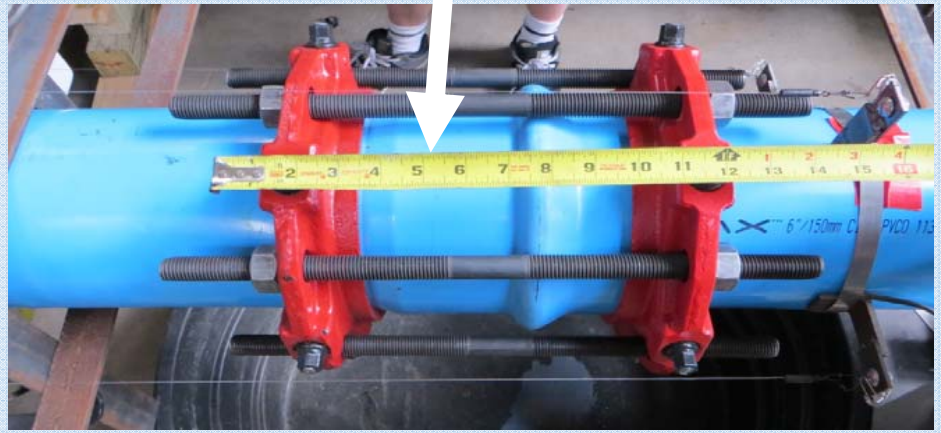
LARGE-SCALE TESTING: NEXT GENERATION INFASTRUCTURE

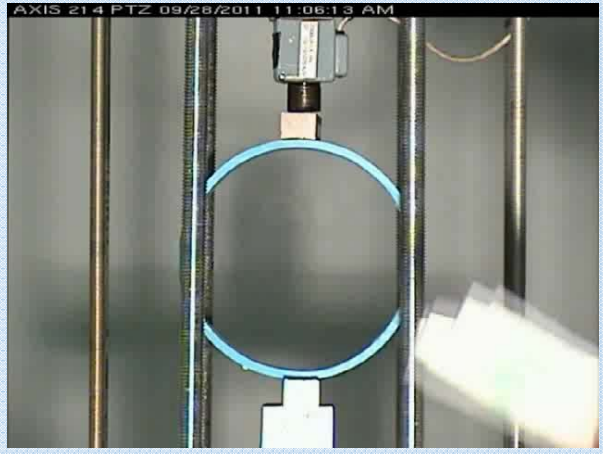


ORIENTED POLYVINYL CHLORIDE (PVCO) JOINTS

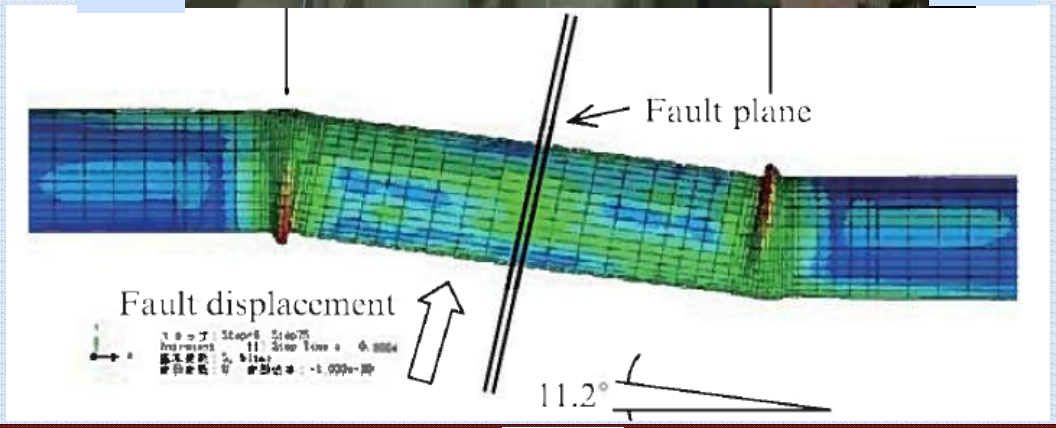


Spigot Compressed into Bell

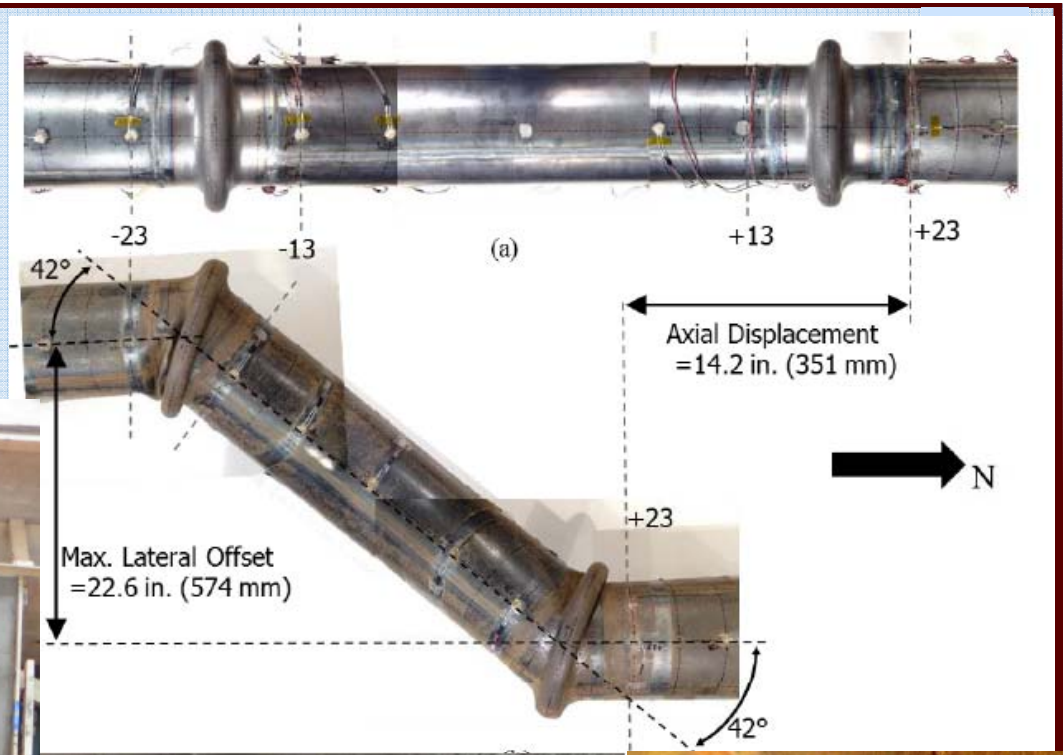


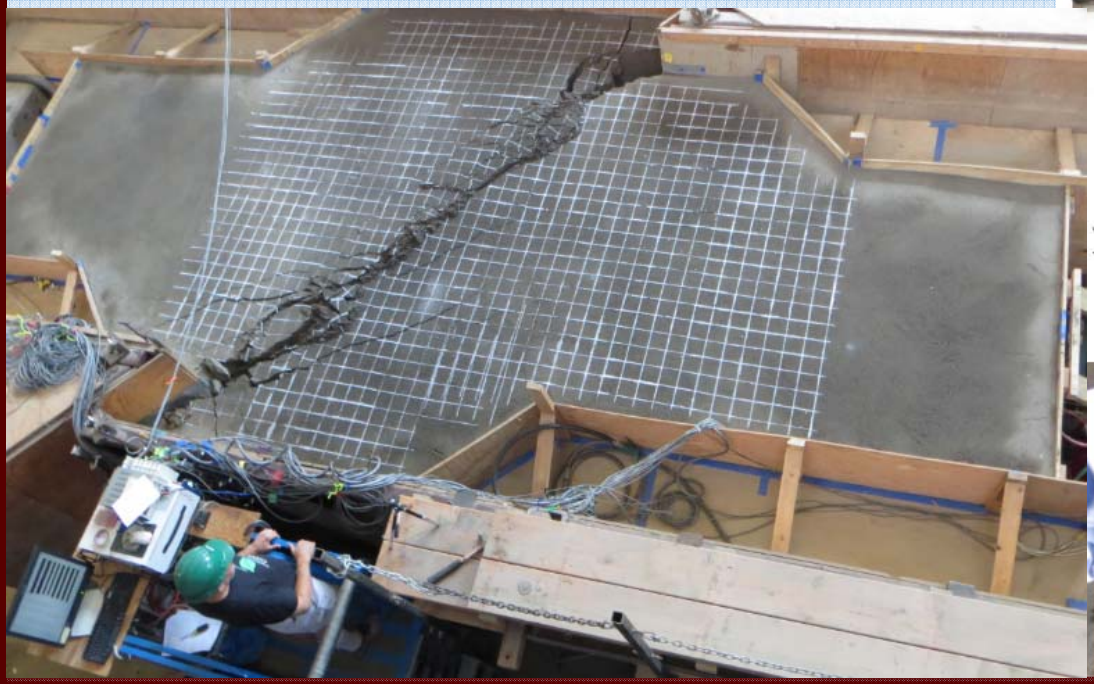


CONTROLLED BUCKLING



CONTROLLED BUCKLING

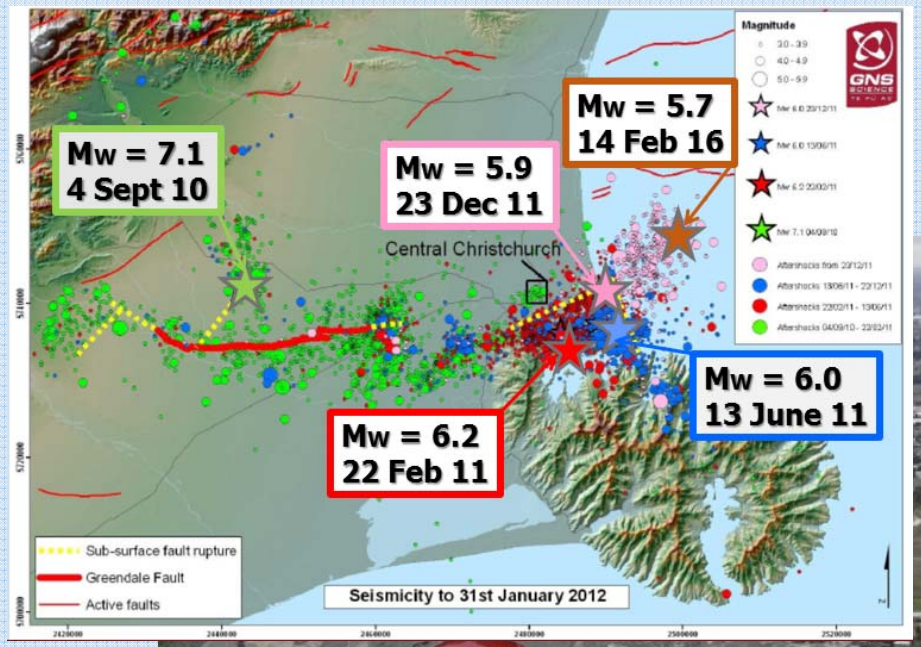




LESSONS: NEXT GENERATION (HAZARD-RESILIENT) PIPELINES

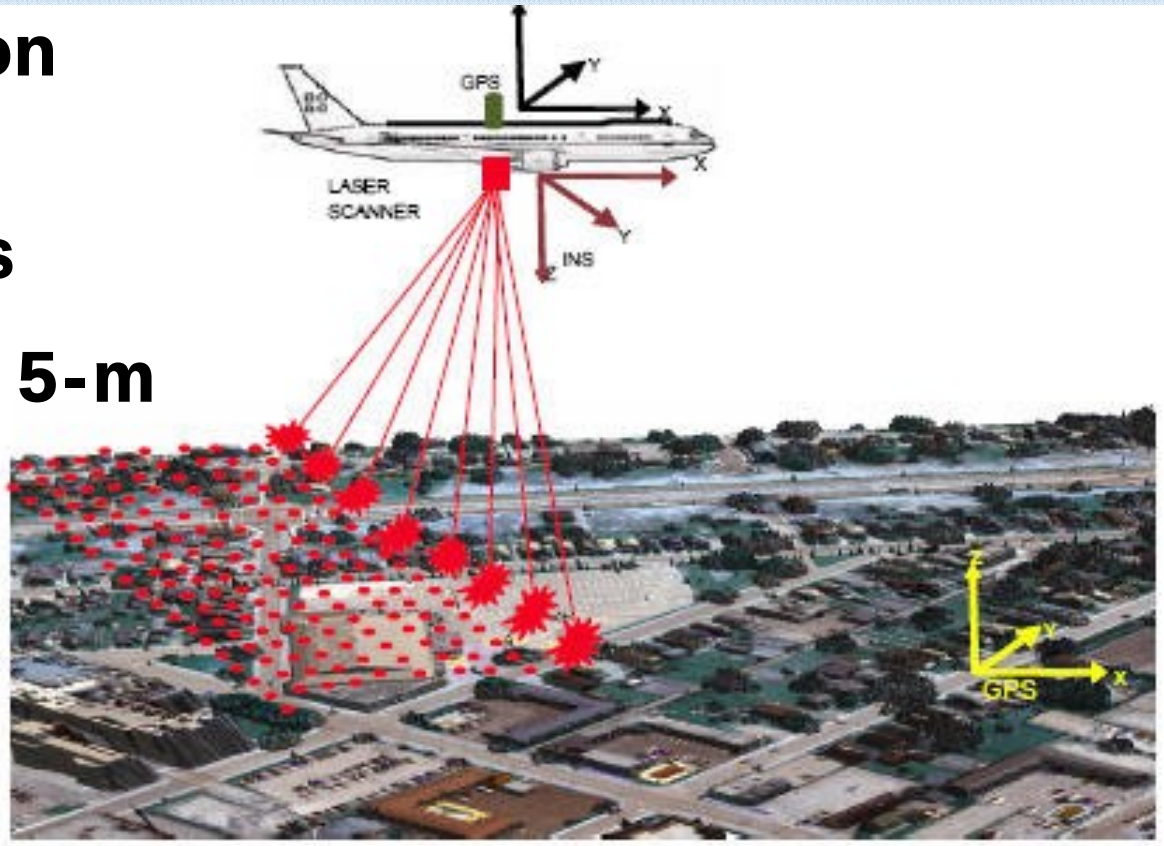
- Paradigm Shift in Pipeline Technology
- Market-Driven Research Funded by Industry
- Can't Have Resilience Unless You Have a Market
- Next Generation Hazard-Resilient Pipeline Simulation Models

CHRISTCHURCH LIQUEFACTION



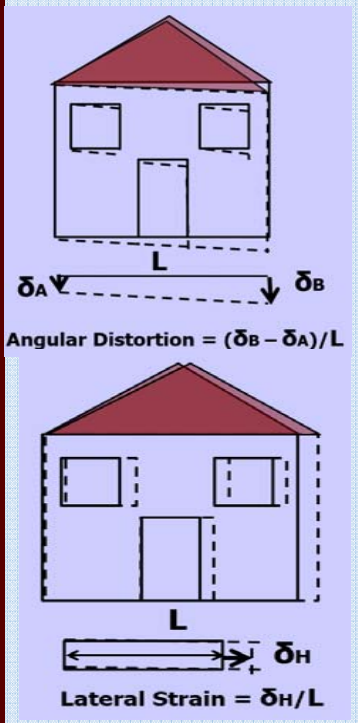
LIGHT DETECTION & RANGING (LiDAR)

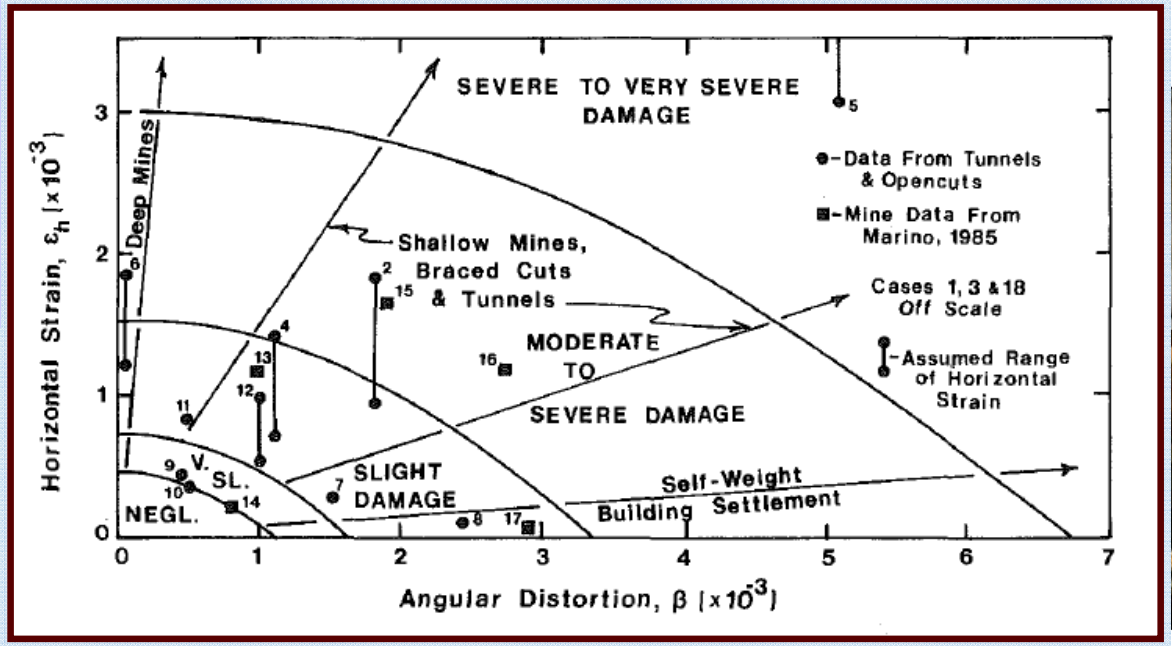
- **High Resolution LiDAR Measurements**
- **Settlement on 5-m**
- **Lateral Movement on 4 & 56-m**



GROUND DEFORMATION METRICS

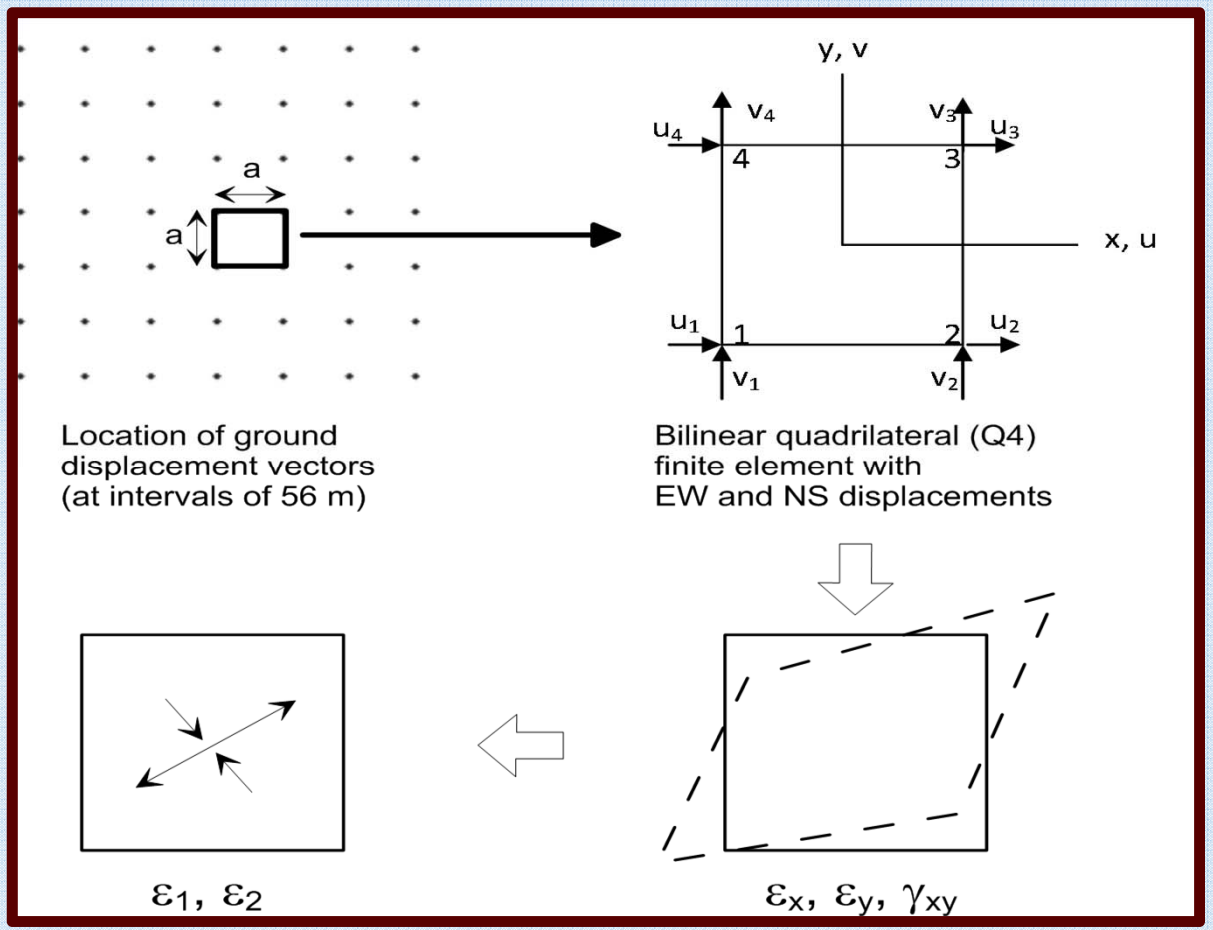
- **From Boscardin & Cording (1989) for Building Damage:**

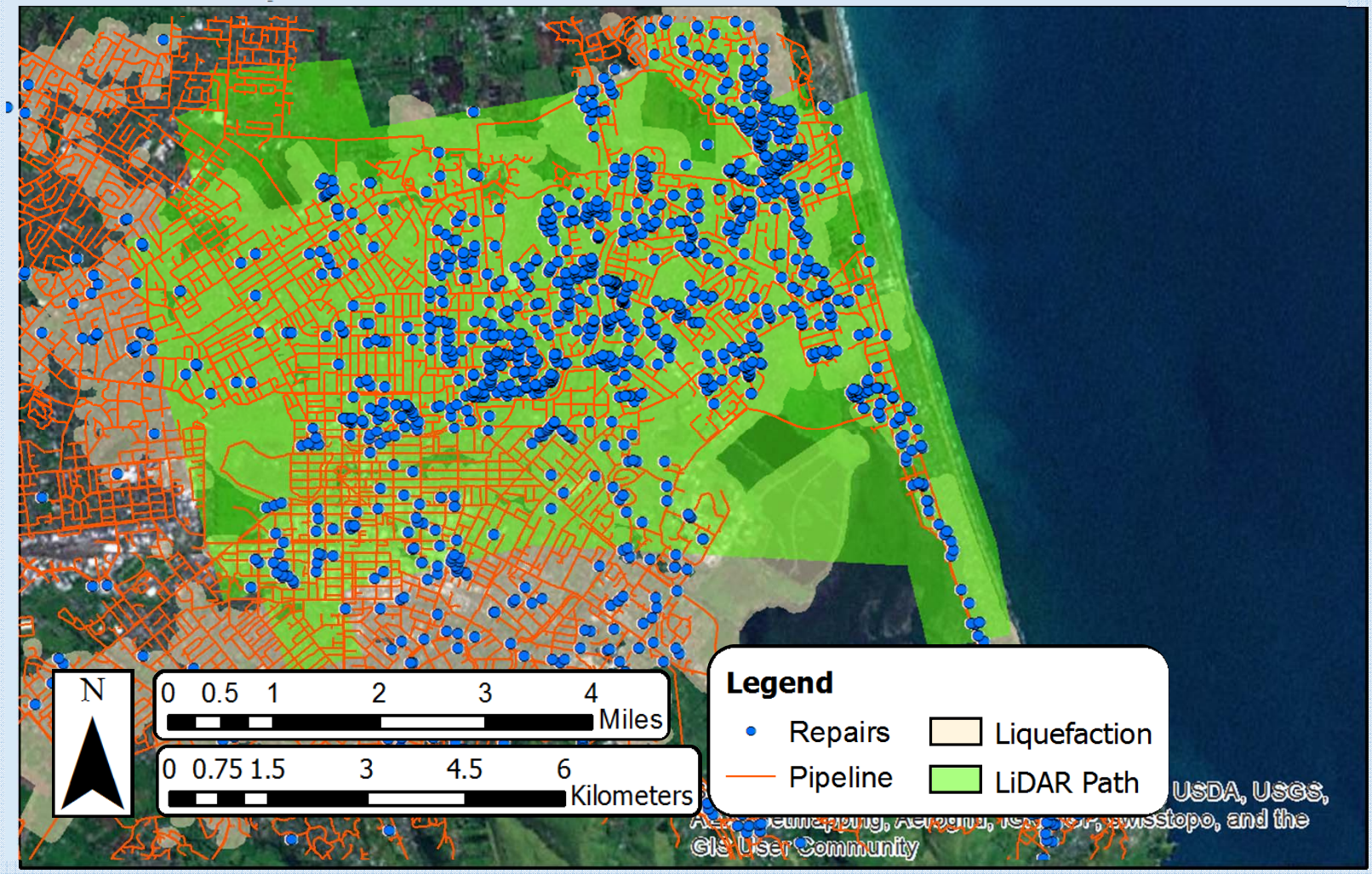




MAXIMUM PRINCIPAL LATERAL STRAIN

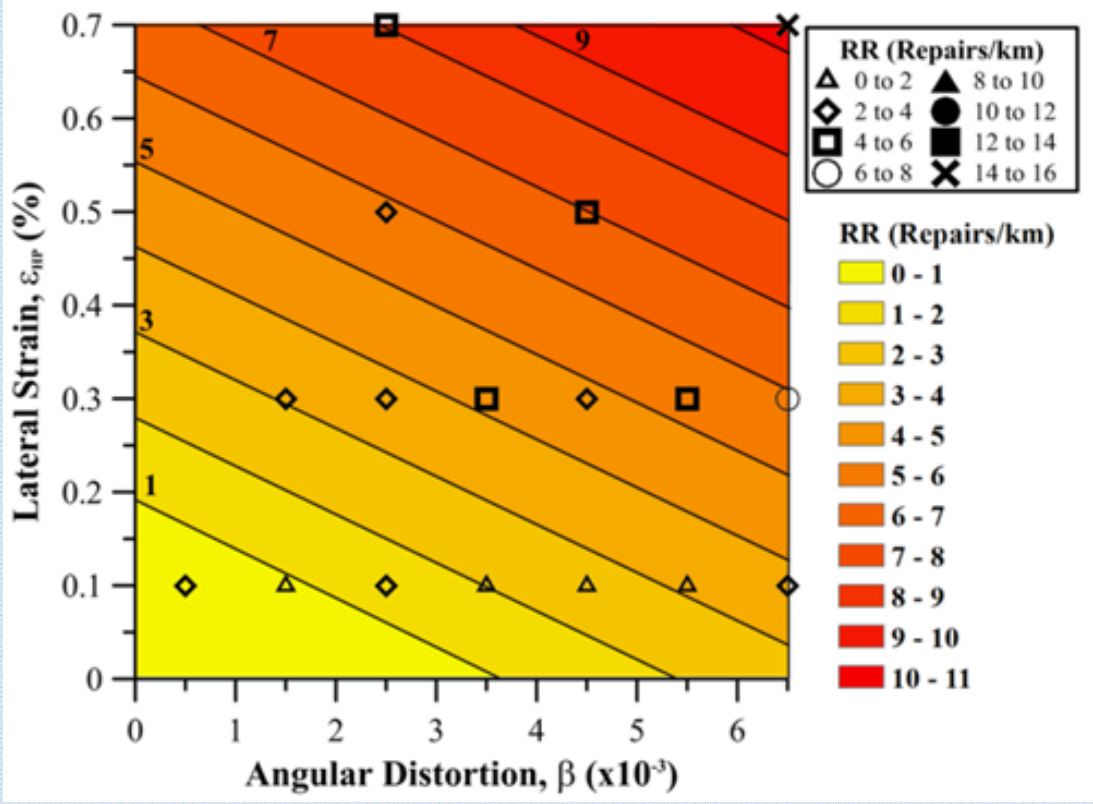
- **Create Bilinear Quadrilateral Finite Element from Lateral Displacements at Grid Corners to Determine Principal Strain**



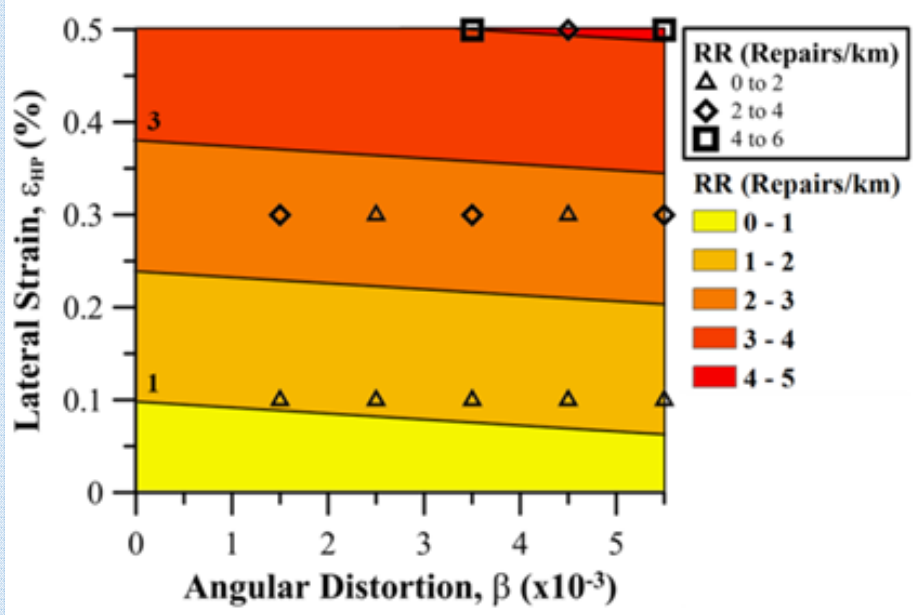

N
0 0.5 1 2 3 4
Miles
0 0.75 1.5 3 4.5 6
Kilometers
Legend
Repairs
Pipeline
Liquefaction
LiDAR Path
USDA, USGS,
GIS User Community

REPAIR RATE FOR COMBINED ANGULAR DISTORTION AND LATERAL STRAIN

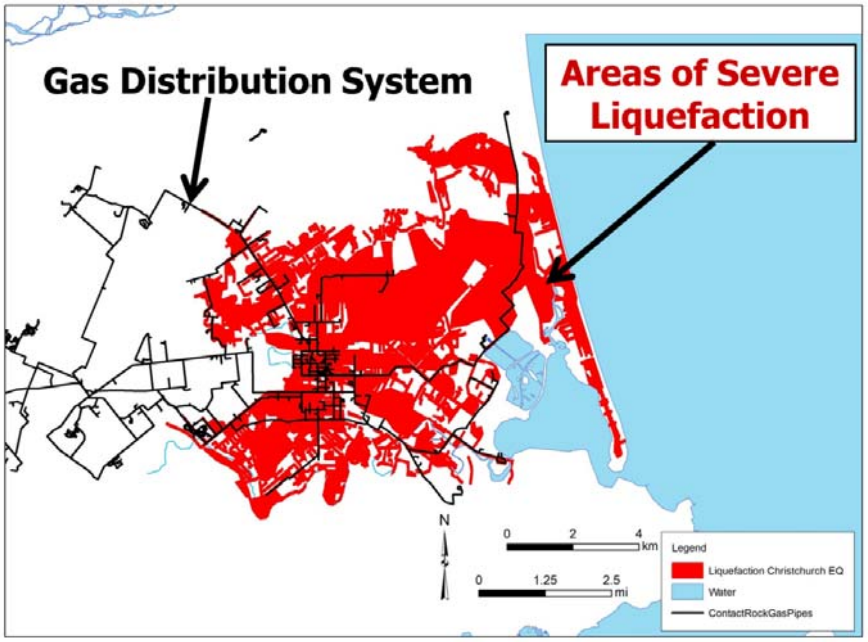
Asbestos Cement (AC) Pipelines

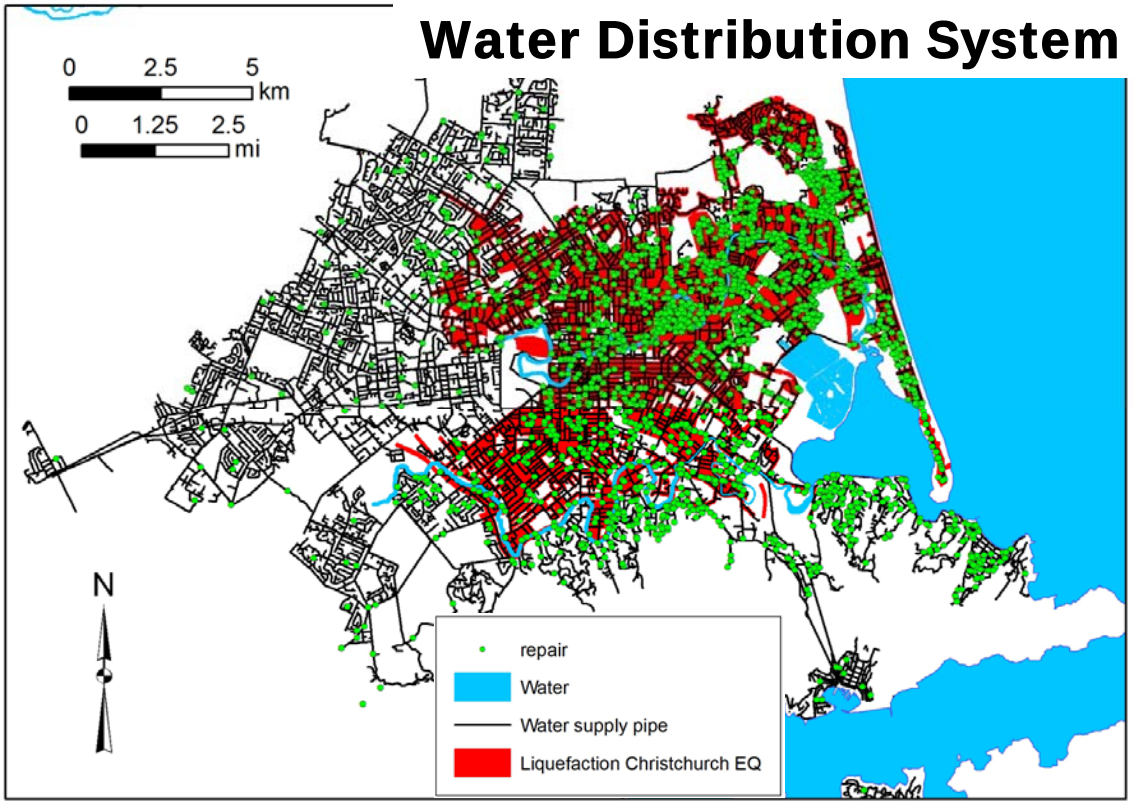


Cast Iron (CI) Pipelines

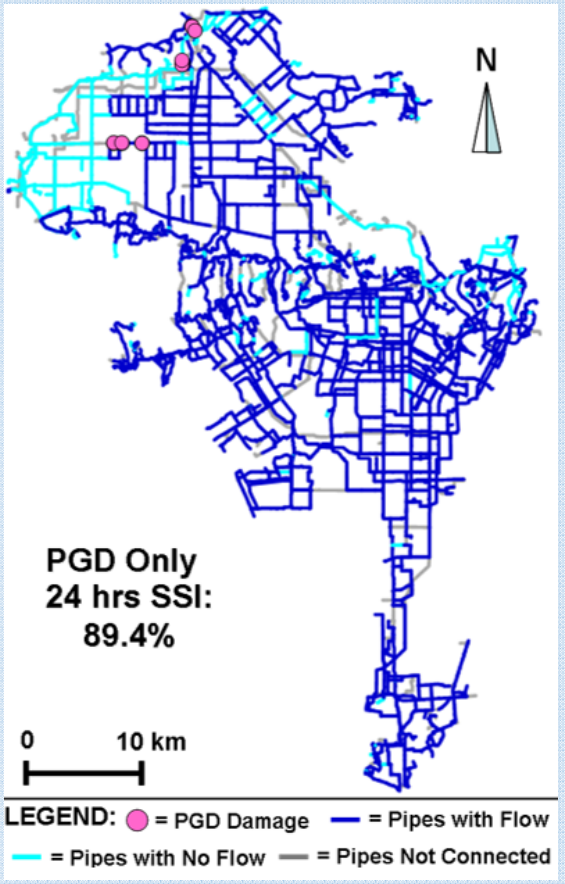


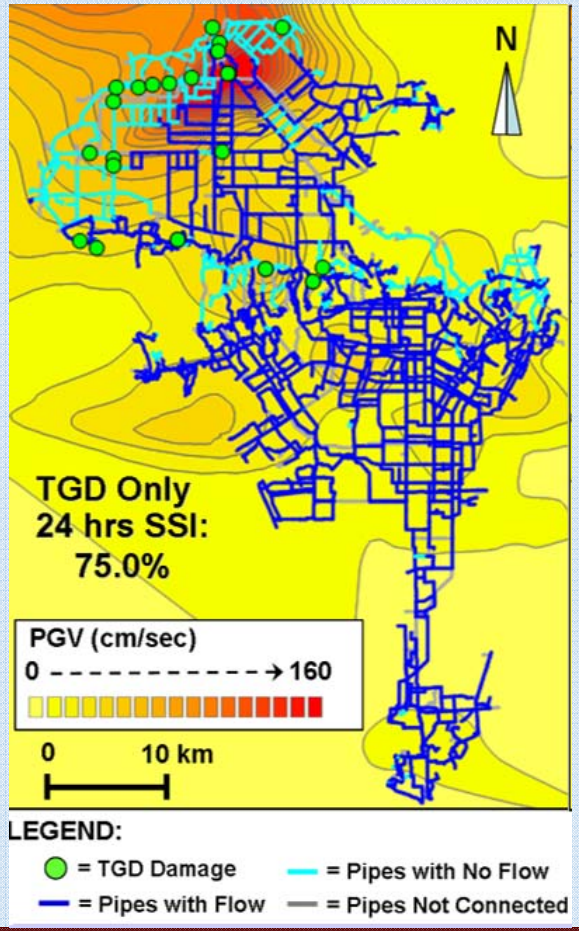
THERMALLY WELDED PE VS CONVENTIONAL JOINTED PIPELINE SYSTEMS

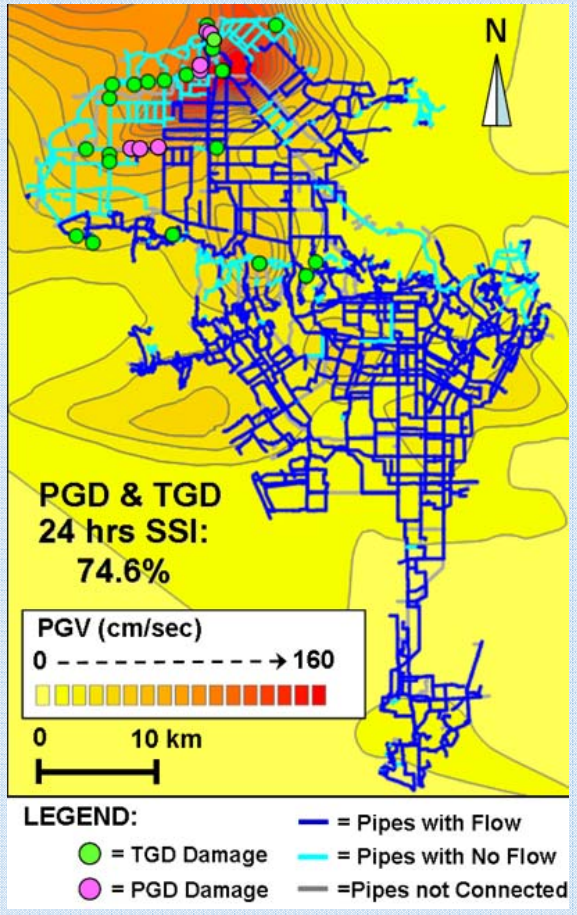




SYSTEMS PERFORMANCE EVALUATION







BEST PATH FORWARD

- Evaluation of Well Documented Case Histories
- Physical Modeling and Experiments Using Large-Scale Testing and Centrifuge Facilities
- Development of Numerical Models for Soil-Pipeline and Soil-Tunnel Interaction Validated by Large-Scale & Centrifuge Testing As Well As Case History Data
- Development of Network Models to Simulate System Performance