Geo-Hazards and Critical Infrastructure

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TOPICS

• Canterbury EQ Sequence
• San Francisco
• Los Angeles
• Critical Infrastructure
NEW ZEALAND
CANTERBURY EARTHQUAKE SEQUENCE

- Mw = 7.1
  4 Sept 10
- Mw = 5.9
  23 Dec 11
- Mw = 6.2
  22 Feb 11
- Mw = 6.0
  13 June 11
CANTERBURY EARTHQUAKE SEQUENCE

- ~ 185 Deaths
- CBD Destroyed
  - ~ 1800 CBD Bldgs. Demolished
  - ~ 55,000 Residences Damaged
- > $30 B Direct Losses, ≈ 20 % GDP
- Massive Liquefaction & Infrastructure Damage

Christchurch
CHRISTCHURCH LIQUEFACTION
LIGHT DETECTION & RANGING

- High Resolution LiDAR Measurements, Corrected for Tectonic Deformation
ANGULAR DISTORTION AND LATERAL STRAIN

\[ \text{Angular Distortion} = \frac{(\delta_B - \delta_A)}{L} \]

\[ \text{Lateral Strain} = \frac{\delta_H}{L} \]
GROUND DEFORMATION METRICS

- From Boscardin & Cording (1989) for Building Damage:
EARTHQUAKE PIPELINE DAMAGE

Asbestos Cement (AC)

Polyvinyl Chloride (PVC)

Cast Iron (CI)

Concrete (CONC)
SCREENING CRITERIA

- Assume Poisson Distribution for Repairs
  \[(1 - \alpha) p \leq (RR)x \leq (1 + \alpha) p\]

  Poisson distribution: \( \mu = (RR)x \), and \( \sigma = [(RR)x]^{1/2} \)

  Sampled repairs follow normal distr. (central limit theorem)

  \[\mu + \phi^{-1}(\beta_c)\sigma = (1 + \alpha)p\]

  \[x \geq [\phi^{-1}(\beta_c)]^2 / \alpha^2 RR\]

- Repair Locations Checked by GIS
- Discount Landslides/ Rockfall Areas
REPAIR RATE VS ANGULAR DISTORTION

Angular Distortion = \frac{(d\nu_1 - d\nu_2)}{L} = \frac{\Delta d}{5m}

Water Pipelines

Wastewater Pipelines

AC Fit Equation:
Y = 0.49 * X + 2.22
R^2 = 0.94

RCRR Fit Equation:
Y = 0.16 * X + 0.81
R^2 = 0.83

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Create Bilinear Quadrilateral Finite Element from Lateral Displacements at Grid Corners to Determine Principal Strain.
REPAIR RATE VS LATERAL STRAIN

Water Pipelines

Wastewater Pipelines

AC Fit Equation: 
Y = 8.04 * X + 2.12
R² = 0.75

CI Fit Equation: 
Y = 8.39 * X + 0.41
R² = 0.89

PVC Fit Equation: 
Y = 6.37 * X + 0.01
R² = 1.00

PVC & UPVC Fit Equation: 
Y = 6.41 * X - 0.01
R² = 0.99

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SCREENING CRITERIA

\[ \mu + \phi^{-1}(\beta_c)\sigma = (1 + \alpha) p \]

\[ x \geq \left[ \phi^{-1}(\beta_c) \right]^2 / \alpha^2 RR \]

- Adjust \( \beta_c \) to obtain sufficient data for each lateral strain and angular distortion combination.
REPAIR RATE, $\beta$, AND $E_{HP}$ FOR CI PIPELINES

CI Pipelines
CI = 60%

RR (Repairs/km)
- △ 0 to 2
- ◊ 2 to 4
- □ 4 to 6
- ○ 6 to 8
- × 8 to 10

Lateral Strain (%)

Angular Distortion ($x10^3$)

CI Pipelines
Repair Rates (repairs/km)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7

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COMPARISON OF AC AND CI RELATIONSHIPS

Angular Distortion ($x10^{-3}$) vs. Lateral Strain (%)

AC Pipelines
Reairs Rate (repairs/km)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14
PALEO CHANNELS

Legend
- Angular Distortion 2.5%
- Pipeline

Pipeline ■ 2.5% Exceedance
LESSONS FROM CHRISTCHURCH

- Extraordinary dataset: multiple EQs, dense ground motion array, massive liquefaction, high density LiDAR, geocoded repairs for thousands of km of different pipelines
- First time comprehensive assessment of underground lifeline response to liquefaction - induced differential vertical movement and lateral strain
- Remarkable performance of highly ductile HDPE and MDPE pipelines
# Earthquake Safety and Emergency Response Bond

## 2010 Earthquake Safety and Emergency Response Bond

<table>
<thead>
<tr>
<th>Projects and Programs</th>
<th>Cost (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWSS Core Facilities</td>
<td>$35.0</td>
</tr>
<tr>
<td>Critical Firefighting Facilities and Infrastructure</td>
<td>$134.3</td>
</tr>
<tr>
<td>Public Safety Building</td>
<td>$243.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$412.3</strong></td>
</tr>
</tbody>
</table>

### Neighborhood Fire Stations
- $65.1 M

### Firefighting Cisterns
- $36.6 M

### Firefighting Pipes and Tunnels
- $32.6 M

**Total CFFI**
- $134.3 M
San Francisco Auxiliary Water Supply System Performance Criteria

- 7.8 Mw Deterministic EQ
- Water Demands in Fire Response Areas
- Monte Carlo AWSS Network Simulations Using GIRAFFE
LESSONS LEARNED FROM SAN FRANCISCO

- Interdependencies of Critical Infrastructure and Geohazards
- Highly Accurate Microzonation through System-wide Characterization of Geotechnical Conditions
- Successful Use of Geotechnical and Hydraulic Network Modeling for Community Protection in Actual Earthquake
Los Angeles Department of Water and Power (LADWP)

- Serves 4.1 Million People
- 12,000 km Distribution & Trunk Pipelines
- 1200 km$^2$
DECISION SUPPORT SYSTEM

- Simulates 12,000 km pipelines & facilities
- Comprehensive seismic & geohazards
- Special software for damaged hydraulic network analysis
- System risk & reliability
- Water & electric interdependencies
- Economic/social impacts

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MULTI-MODAL SIMULATION

Simulation for Ground Failure, Accidents, Human Threats

Probabilistic Simulation for System-wide Seismic Wave Effects

Combined Simulation for Permanent Ground Deformation & Seismic Wave Effects
VALIDATION: 1994 NORTH RIDGE EARTHQUAKE

- System Serviceability
  - Results agree with LADWP records

- Geographic Distribution of Lost Water Service
  - ~90% match with actual records

- Flow at Key Locations
  - Excellent agreement with records
SHAKEOUT SCENARIO

7.8 M\text{\textit{w}} San Andreas Fault Earthquake

SCEC ShakeOut Simulation by R. Graves

Ground velocity magnitude

- 0.05
- 1
- 2 m/s
FLOW CONDITIONS

(a) 0 Hrs

Flow and Demands

- Pipes
- Damaged
- Flow
- Nonfunctional
- Unsatisfied Demands

0 10 km

(b) 24 Hrs

0 10 km
WATER SERVICE AREAS

Results for 15 Service Areas

Serviceability Index

WSA SI
0 hours
24 hours

Water Service Areas

Harbor
Central City
Westside
Santa Ynez
Santa Monica
Valley Floor A
Hollywood Hills
Mt. Washington
Highland Park
Encino Hills
Granada Hills
Sunland-Tujunga
Foothills
Valley Floor B
Valley Floor C

0 10 km
EMERGENCY USE OF RESERVOIRS

SI for most populated areas of Los Angeles (Westside, Central City, Highland Park, and Mount Washington) performance with reservoirs on and off
LESSONS LEARNED FROM LOS ANGELES

- State-of-the-Art Decision Support System
- Emergency Response Strategy for Major Earthquakes
- Key Aspect of Organization Resilience Is Ability to Improvise
SOUTHERN CALIFORNIA WATER SUPPLY

- Southern California highly dependent on imported water
  - Population: 22 Million

70% Imported Water:
- California Aqueduct
- Los Angeles Aqueducts
- Colorado River Aqueduct

30% Ground Water
LOS ANGELES AQUEDUCTS

- 3.3m Horizontal Fault Displacement
- 2.9m Wide Elizabeth Tunnel
  - Cuts off tunnel
LA WATER SUPPLY CROSSES SAN ANDREAS FAULT

- San Joaquin Valley
- Lake Hughes
- Palmdale
- Ventura
- Los Angeles
- San Bernardino

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RESILIENCE

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