

2015 National Lifelines Forum, Christchurch, 21 - 22 October 2015

## What have we really learned about the vulnerability of horizontal infrastructure to liquefaction ?

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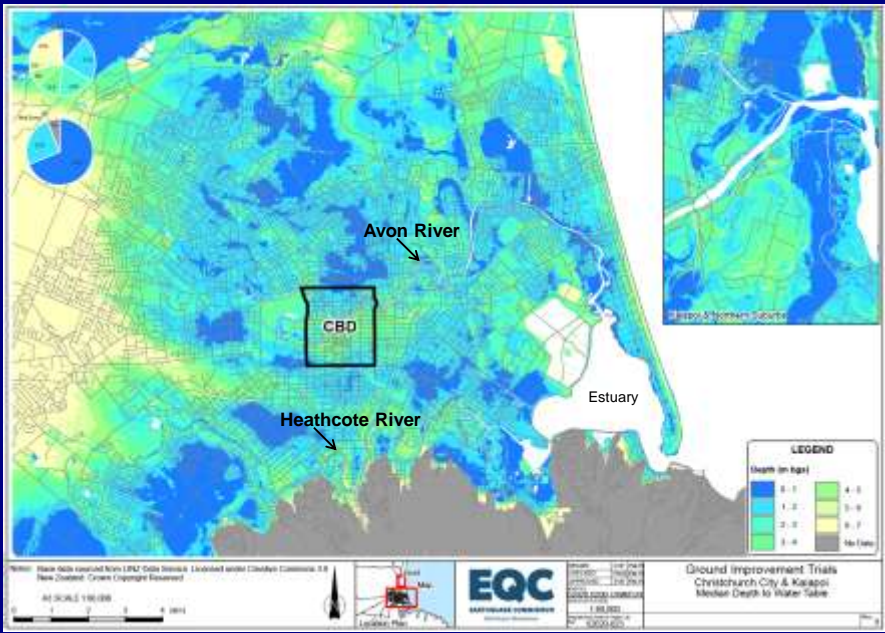
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**Misko Cubrinovski,  
Matthew Hughes**

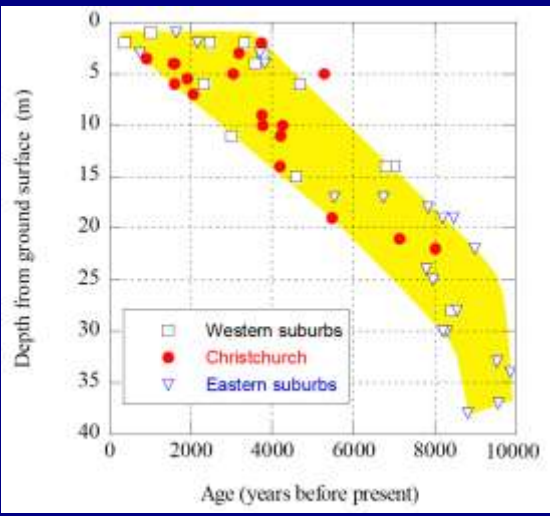
**University of Canterbury,  
Christchurch, New Zealand**

## **Context (Canterbury Earthquakes)**

# Shallow Water Table



# Young and Loose Soils



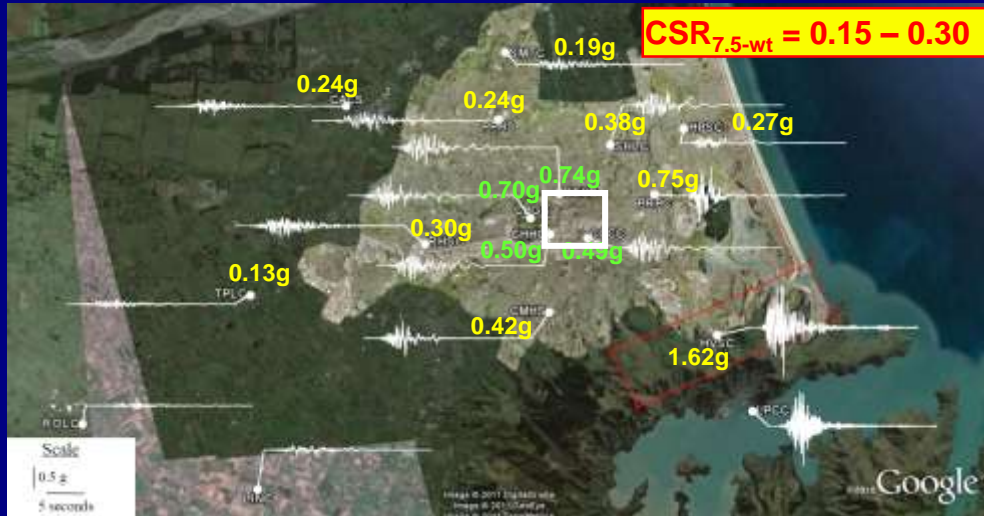
**High liquefaction potential!**

Cubrinovski and McCahon (2011; CERC Report); based on compiled data from Brown & Weeber, 1992)

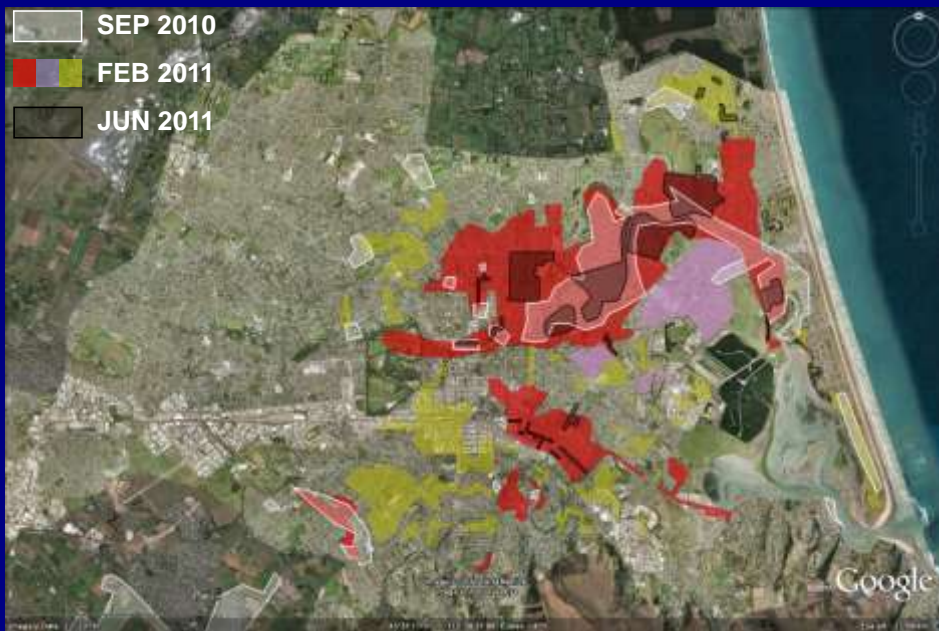
# Severe Ground Motions



22 February 2011 Earthquake ( $M_w$  6.2)



# Unprecedented Liquefaction in Urban Setting



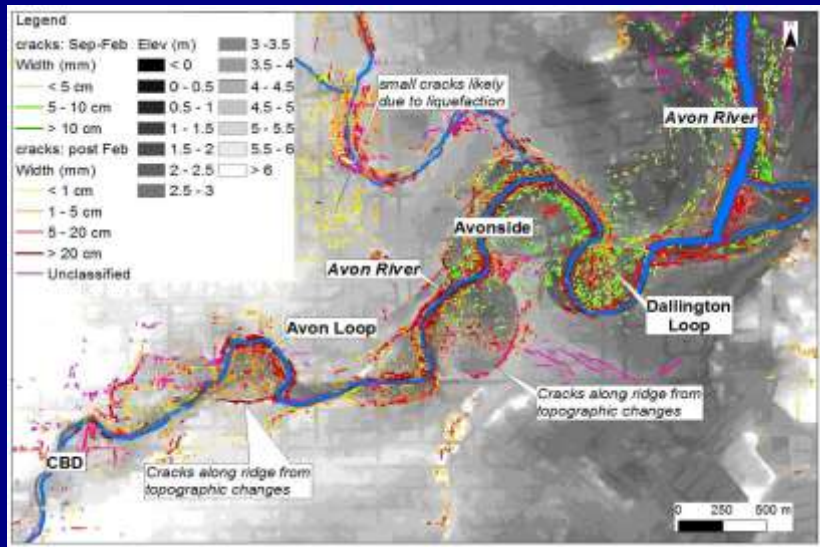
# Lateral Spreading

## Impacts of Lateral Spreading on Structures



Cubrinovski et al. (2012)

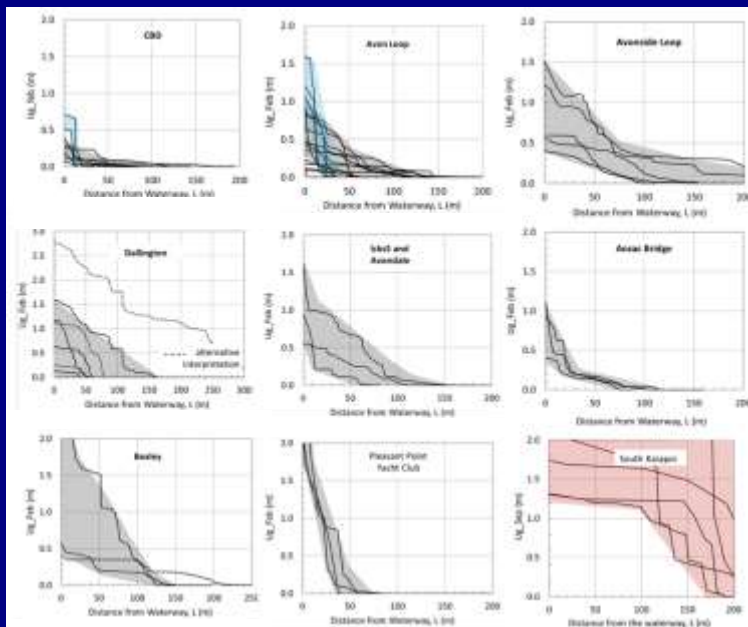
# Ground Cracks along the Avon River



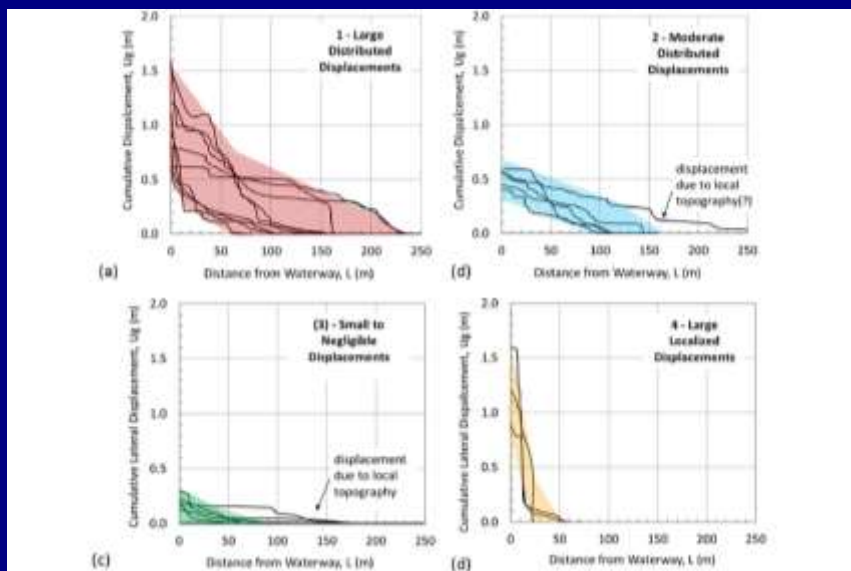
# Spreading Measurements along the Avon River



# Lateral Spreading along the Avon River



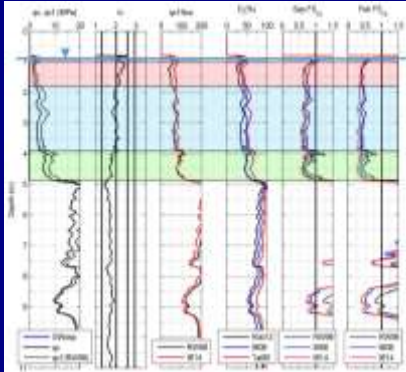
# Classification of Lateral Spreads



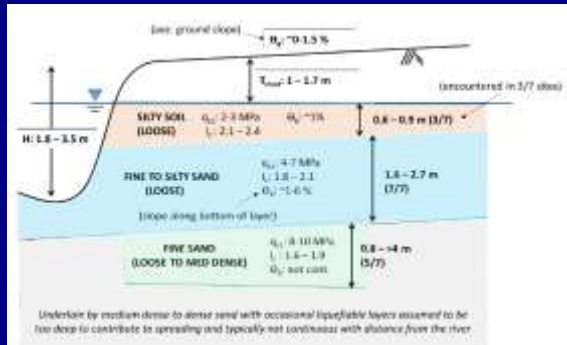
# Characterization of Large Lateral Spreads



## Characteristic Soil Profile



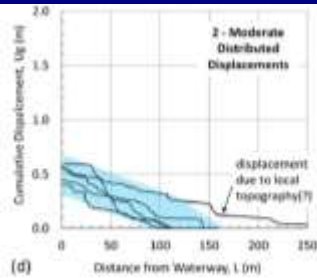
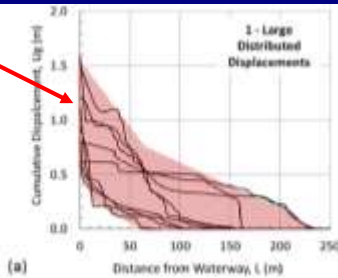
## Critical Soil Layer



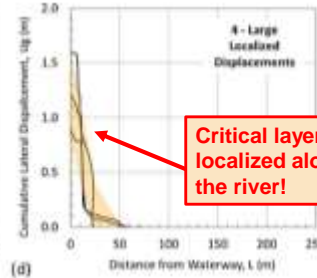
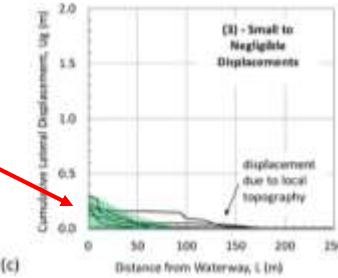
# Interpretation of Lateral Spreads



Three layer stratigraphy with critical layer!



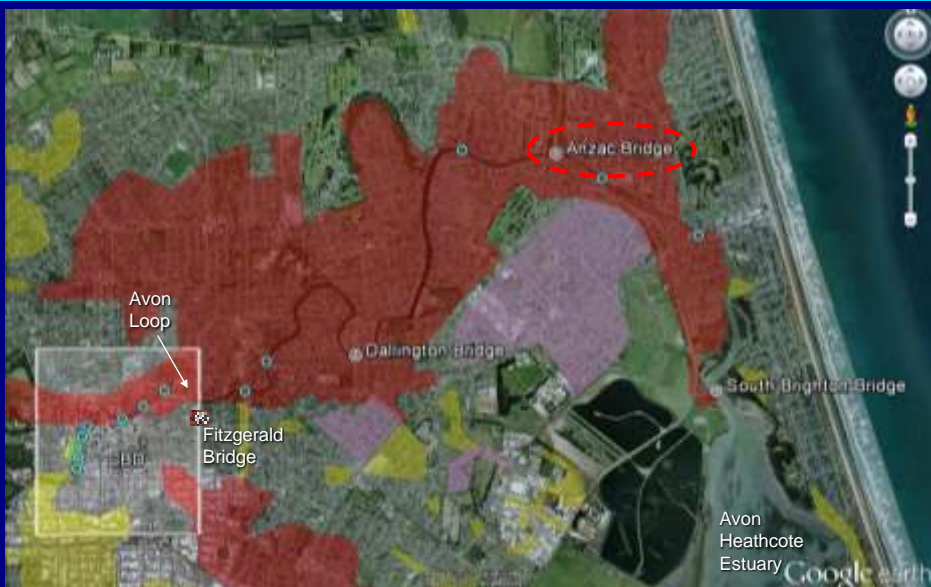
Critical layer either absent or thin and not continuous!



Critical layer localized along the river!

# Short-Span Bridges

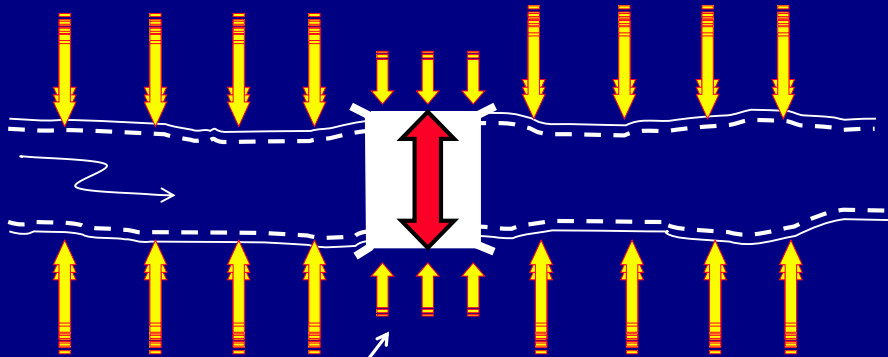
## The Avon River Bridges



Cubrinovski et al. (2014) ASCE J. of Constructed Facilities  
Cubrinovski et al. (2014) EQ Spectra



## Spreading-induced Damage Mechanism - 1



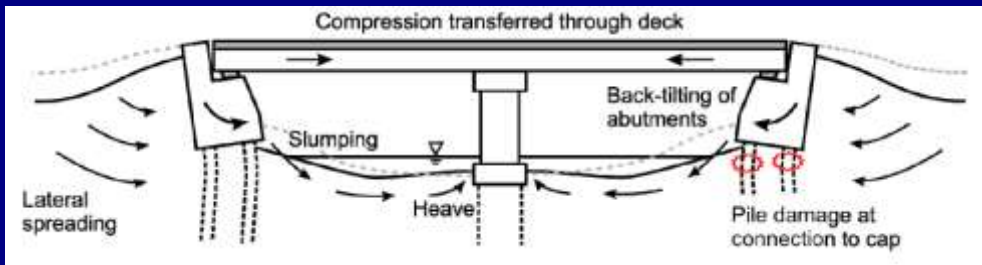
Reduction in spreading displacements  
by the stiff bridge structure

- short, two or three span bridges,  
 $L = 25 - 50 \text{ m (65m)}$

## Spreading-Induced Damage Mechanism - 2



- Short span/length bridges; two or three spans,  $L = 25 \text{ m} - 50 \text{ m (65m)}$
- Stiff/robust superstructure with high capacity to resist lateral loads



**Deck-strutting → Abutment inward-rotation → Pile displacement  
→ deformation → damage**

Cubrinovski et al. (2014) ASCE J. of Constructed Facilities  
Cubrinovski et al. (2014) EQ Spectra

# Anzac Bridge

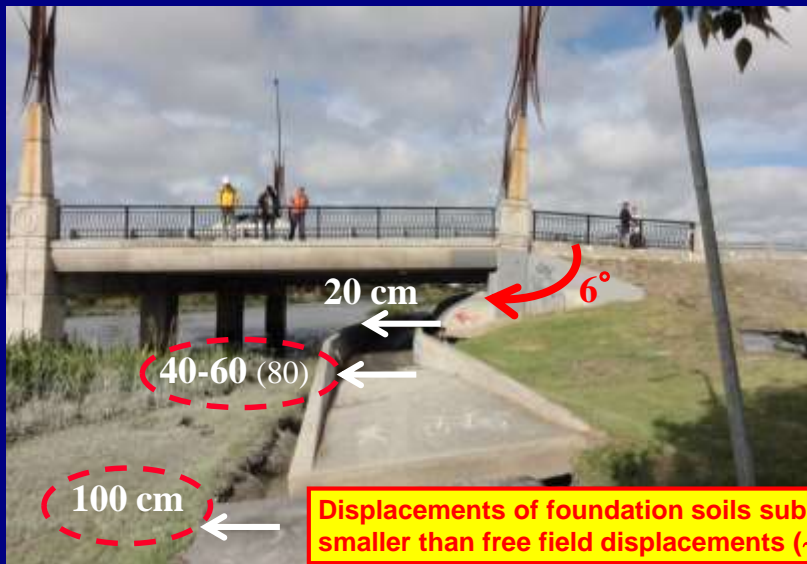


2011 Christchurch earthquake (aerial view 3/03/11)



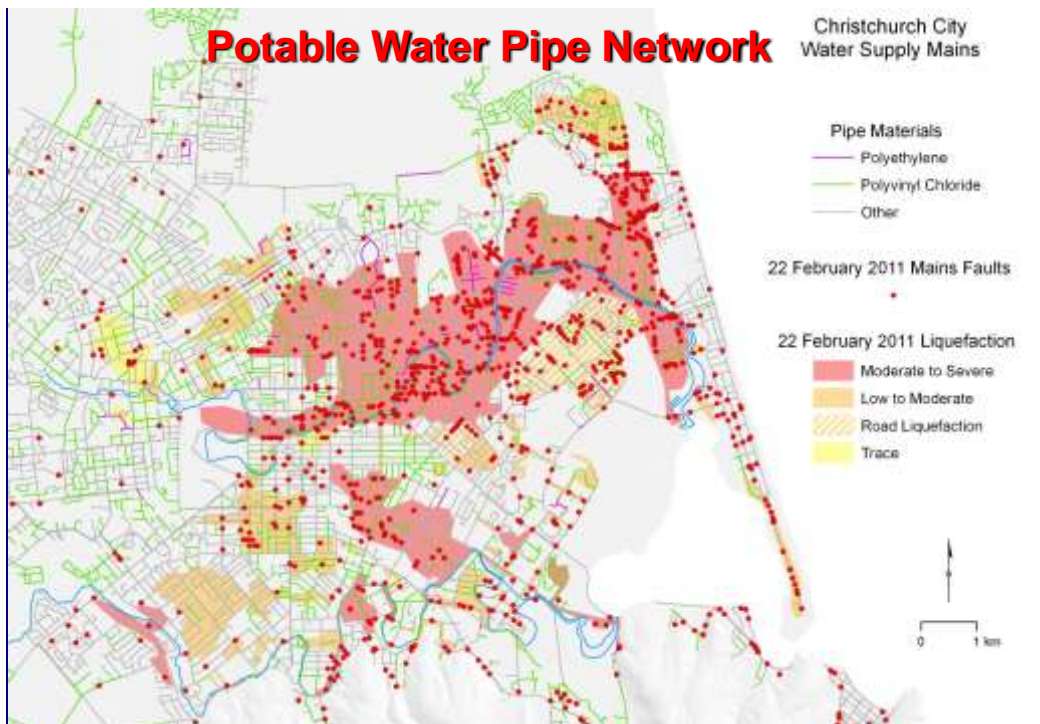
Cubrinovski et al. (2014) EQ Spectra Special Issue

# Design Considerations

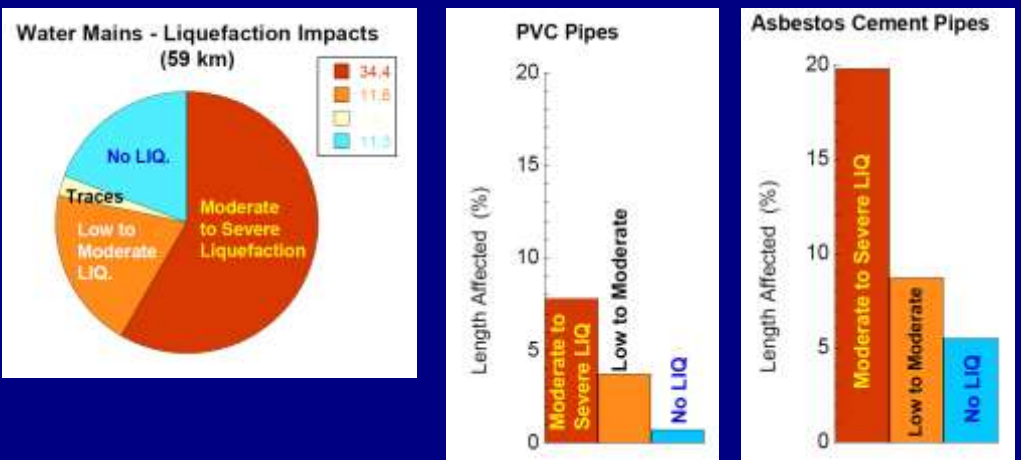


Cubrinovski et al. (2014) EQ Spectra Special Issue

# Pipe & Road Networks

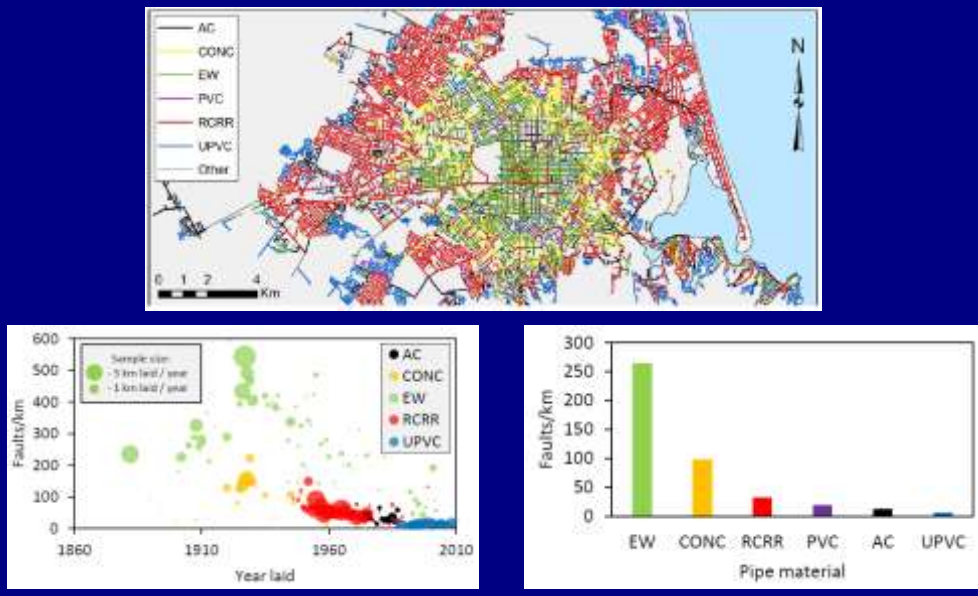


# Water Mains – Effects of Liquefaction

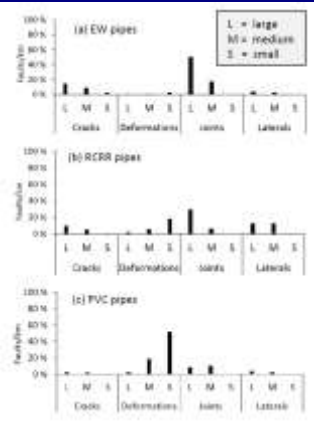
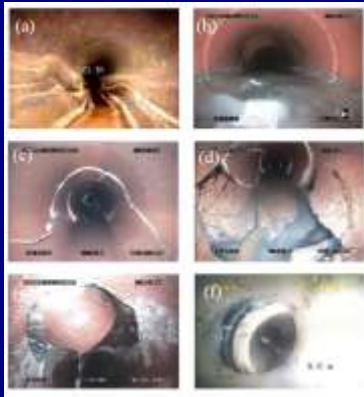
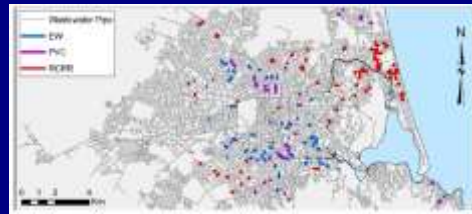


**Ductile (flexible) pipelines vs. brittle pipelines**

# Wastewater Pipes (age & materials)



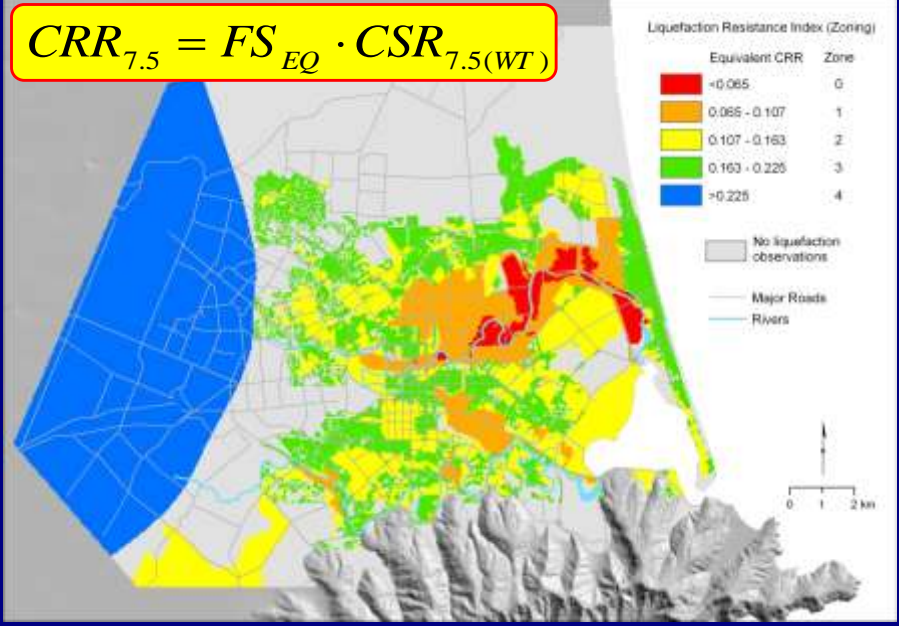
# Wastewater Pipes (CCTV data)



# Liquefaction Resistance Index (LRI)



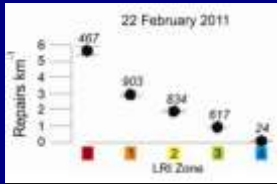
$$CRR_{7.5} = FS_{EQ} \cdot CSR_{7.5(WT)}$$



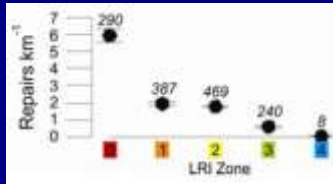
# Damage vs. LRI correlation



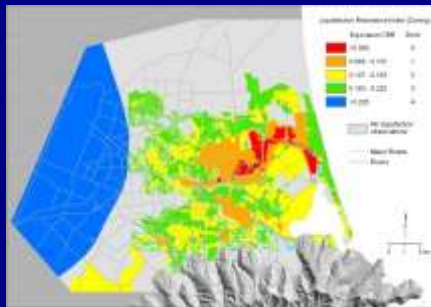
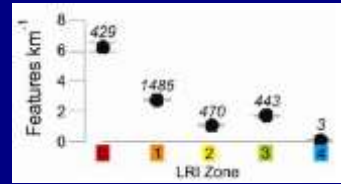
Potable water mains



Wastewater pipes



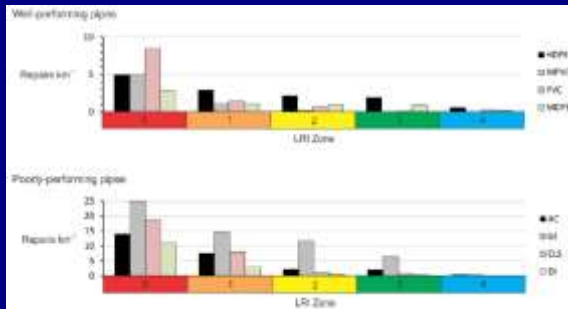
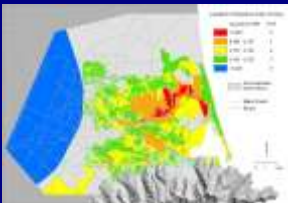
Ponding of roads



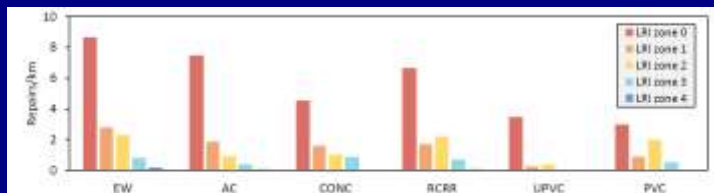
# Damage vs. LRI (different pipe materials)



Potable water mains



Wastewater pipes



# Concluding Remarks



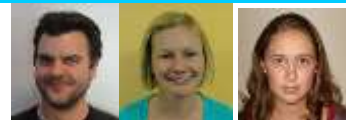
- Extreme effects of liquefaction (both extent and severity)
- Lateral spreading
  - Soil properties and stratification
  - Ability to identify the potential and reasons for large/moderate spreads
- Damage (deformation) mechanisms
  - Soil-foundation-abutment-deck interaction for bridges (system response)
  - Pipe materials, connection details, (flexible vs. brittle pipelines)
- Systematic approach is needed
  - Earthquake loads (from ground deformation/failure)
  - Susceptible ground conditions (critical features)
  - Component and system responses (materials, details, mechanisms)
  - Ability to quantify relative performance
  - LRI methodology/relationships (transferable to other areas)

## Acknowledgements



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