



Geotechnical Extreme Events Reconnaissance
Turning Disaster into Knowledge



CHALLENGE III

Liquefaction-Induced Building Settlement

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etc.**

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Liquefaction-Induced Building Movements

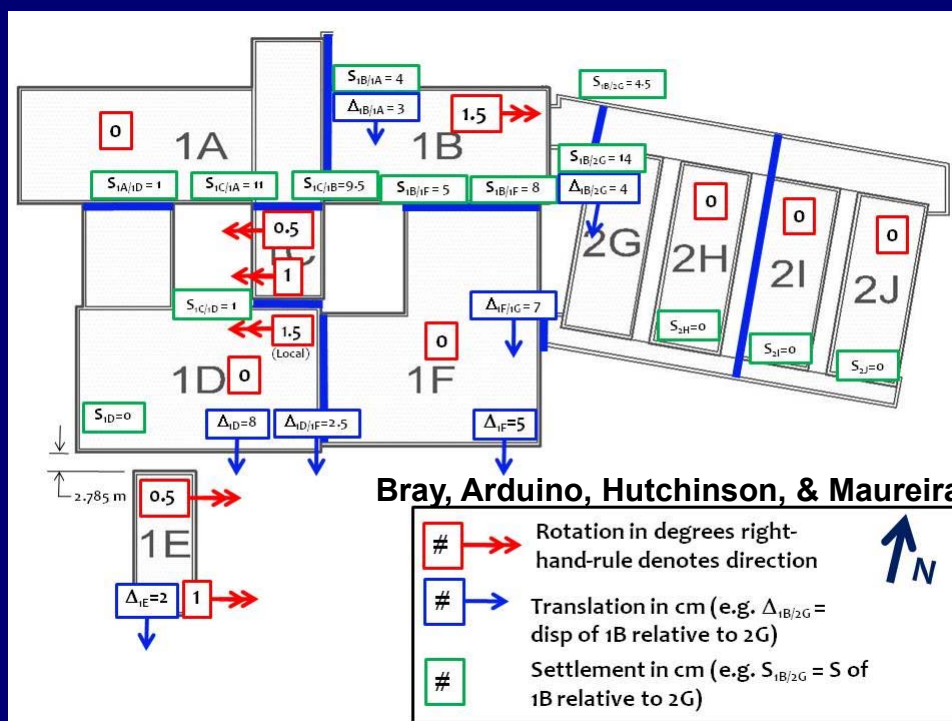
March 11, 2011 Tohoku, Japan Earthquake ($M_w = 9.0$)



Tokimatsu et al. & GEER (Ashford et al. 2011)

Effects of Buildings on Soil Liquefaction

Hospital in Curanilahue 2010 Maule Chile EQ



Liquefaction-Induced Building Settlement

1. What is the current state-of-the-art for evaluating this problem?

RECOMMENDED APPROACH

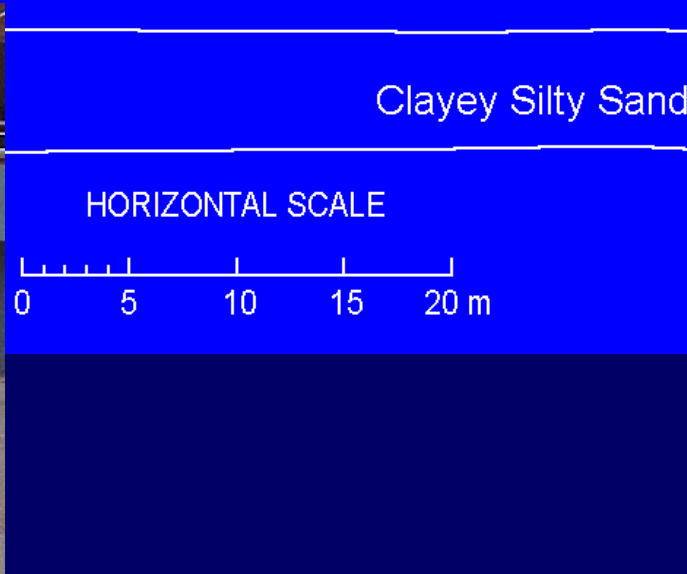
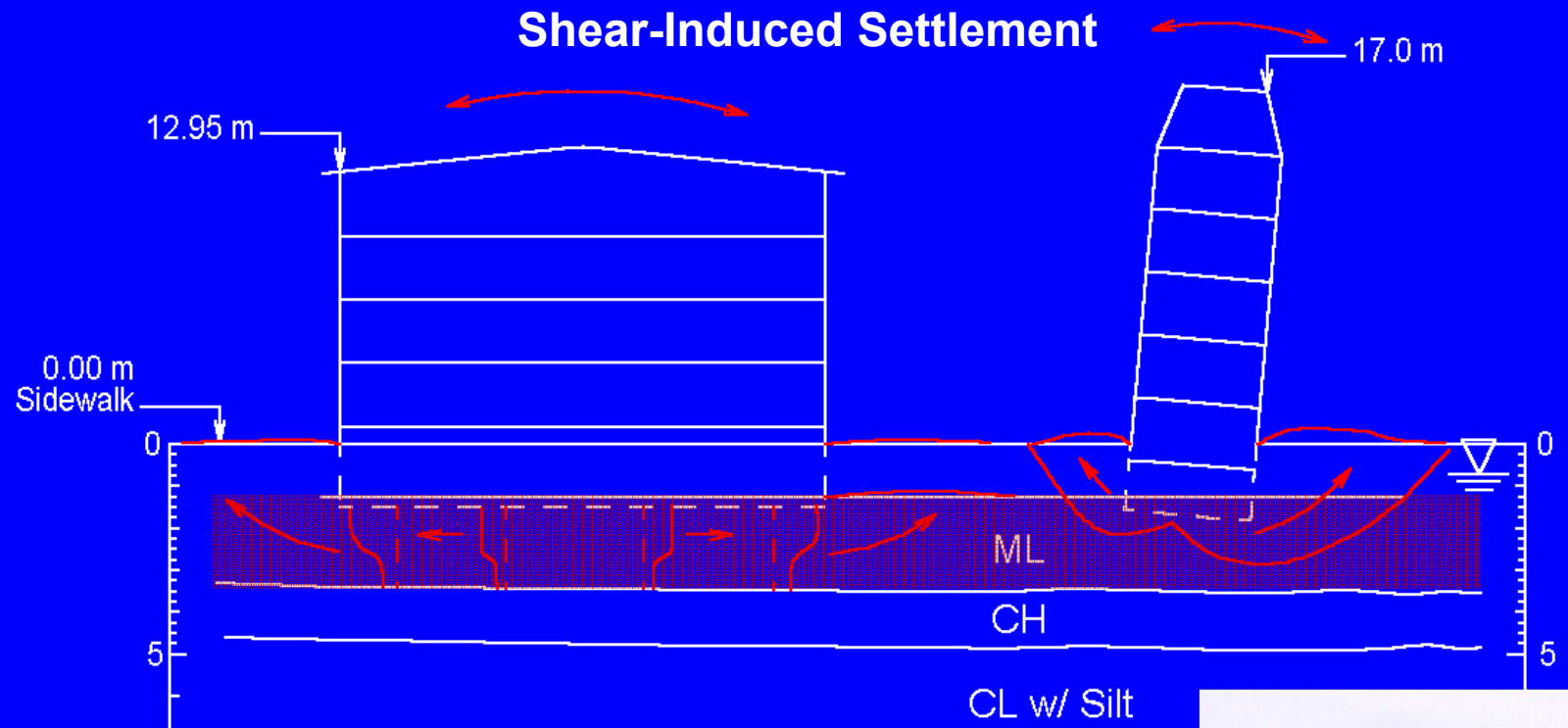
Gain insight through analyses & experience (Bray et al. 2017):

1. Perform liquefaction triggering and calculate 1D post-liquefaction reconsolidation settlement
2. Estimate ejecta-induced settlement (e.g., LSN, Ishihara 1985)
3. Perform bearing capacity analysis using post-liquefaction strength; if $FS < 1.5 - 2.0$, large movements likely
4. Perform nonlinear effective stress SSI analyses to estimate building movements that captures shear-induced deformation; requires good soil and EQ characterization
5. Use engineering judgment based on understanding site geology, key mechanisms, & case histories

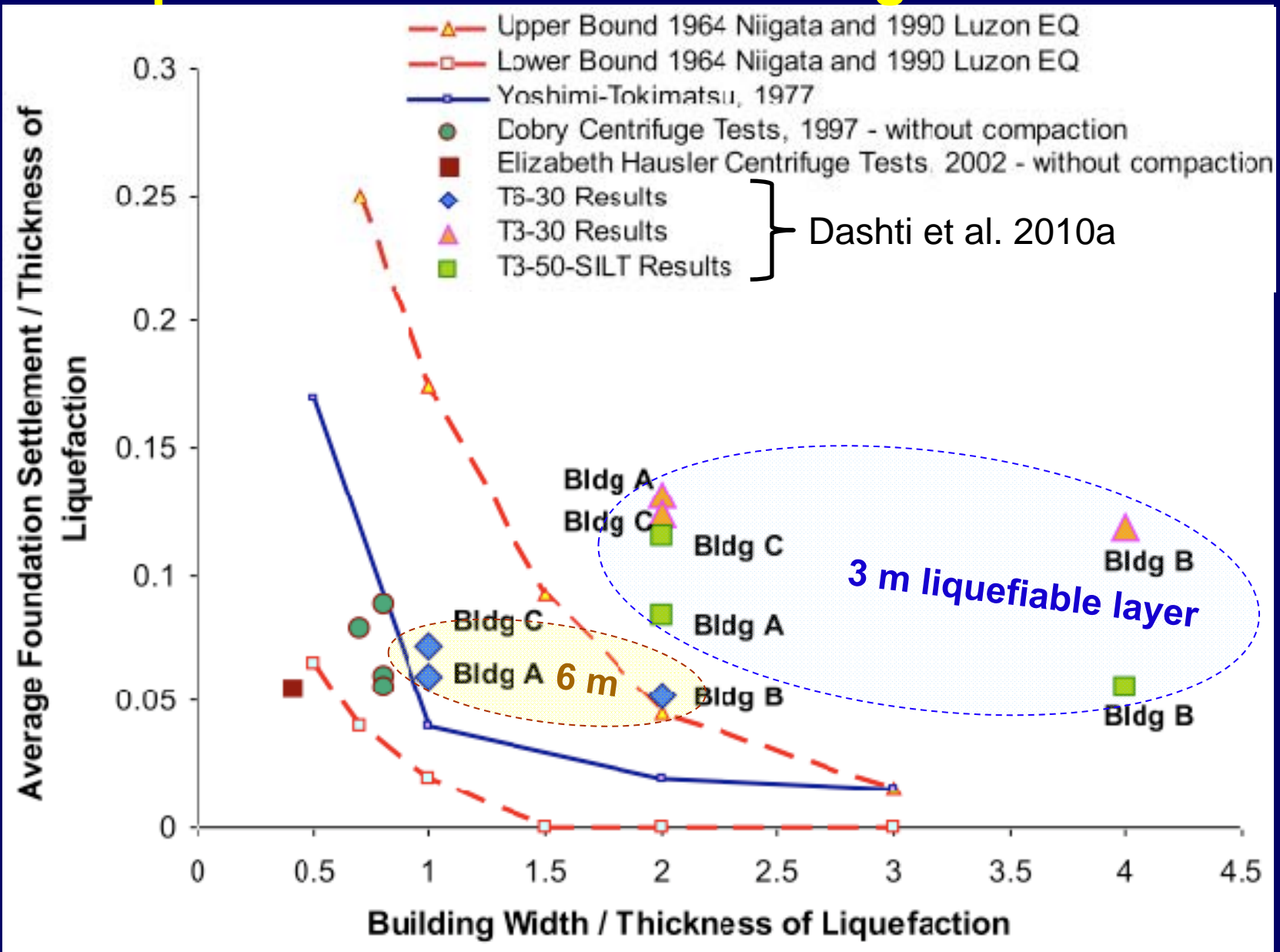
Liquefaction-Induced Building Settlement

3. What are the primary mechanisms involved in the phenomenon?

Building Response in Adapazari - 1999 Kocaeli EQ



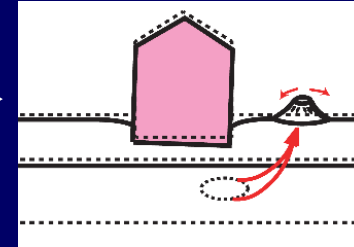
Liquefaction-Induced Building Settlement



Overly Focused on Liquefied Layer Thickness

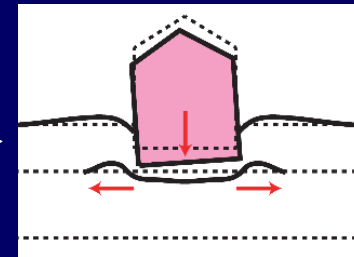
DISPLACEMENT MECHANISMS

1. Ground Loss due to Ejecta

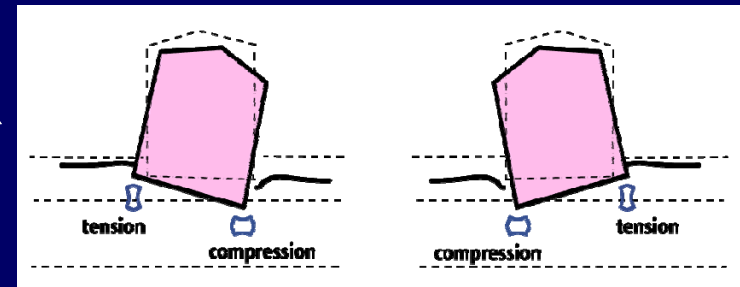


2. Shear-Induced Deformations

Bearing Capacity Failure (ϵ_{q-BC})

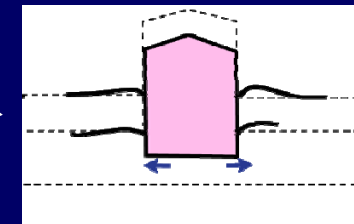


SSI-Induced Ratcheting (ϵ_{q-SSI})



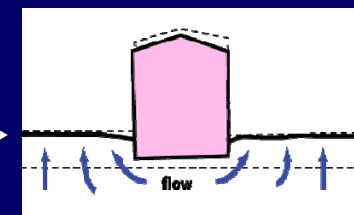
3. Volumetric Deformations

Partial Drainage (ϵ_{p-DR})



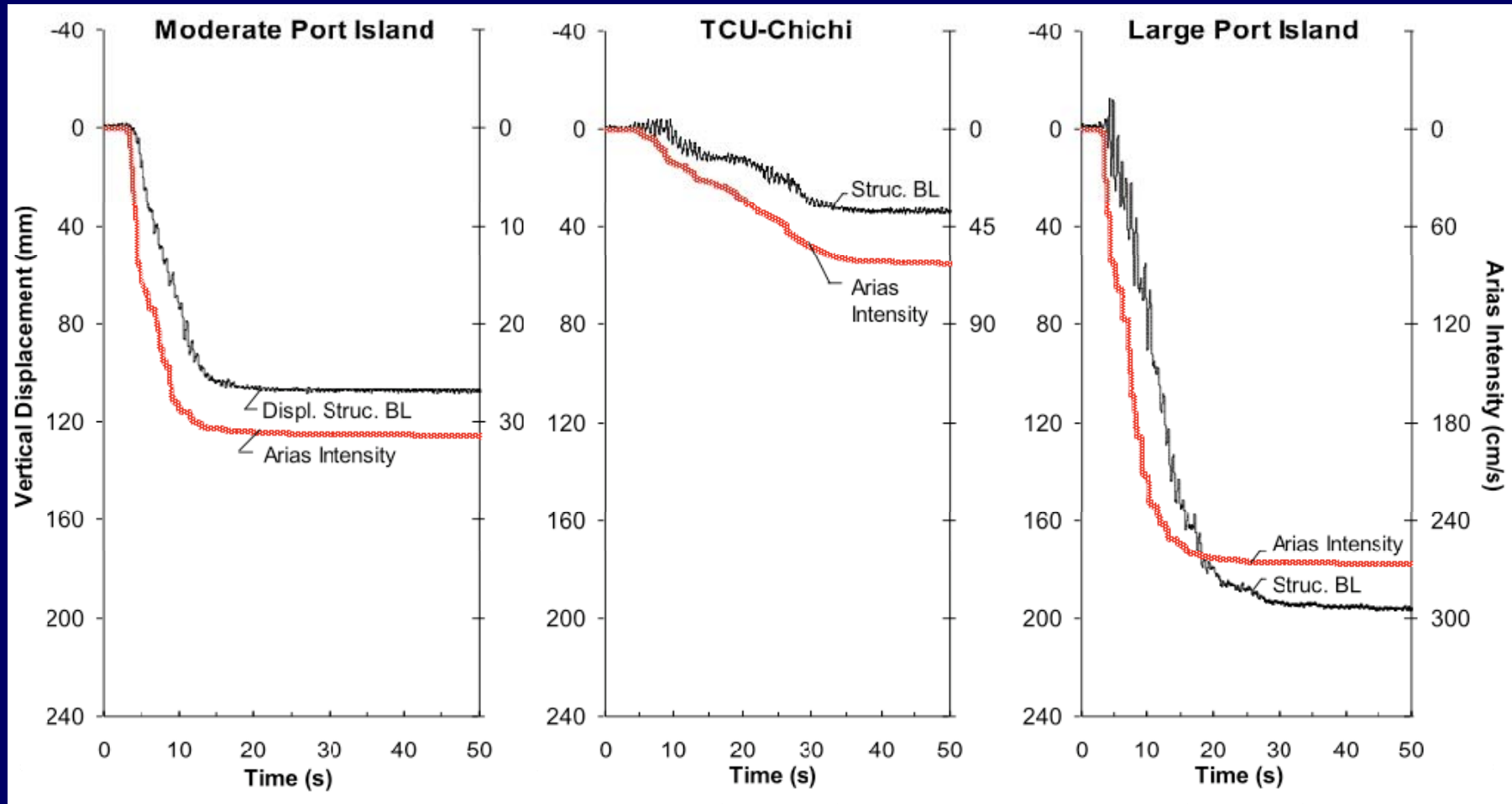
Sedimentation (ϵ_{p-SED})

Consolidation (ϵ_{p-CON})



Effects of Ground Motion

Dashti et al. 2010b



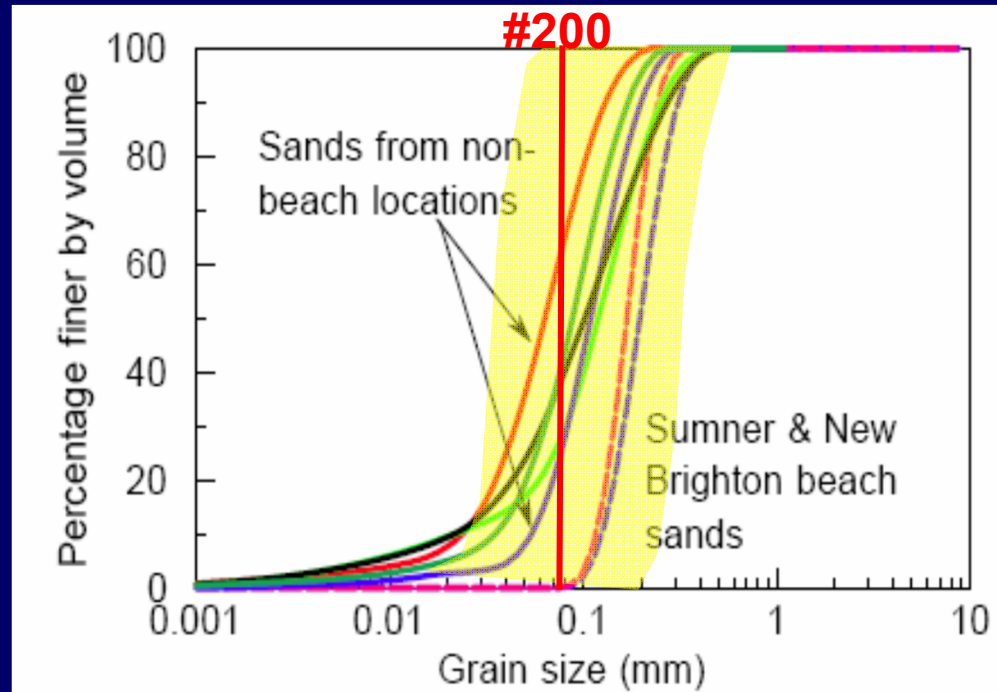
$$\text{Shaking Intensity Rate} = \text{SIR} = I_{a_{5-75}} / D_{5-75}$$

Liquefaction-Induced Building Settlement

2. What are the key underlying geologic processes that affect it?
4. What are the key challenges to developing better evaluation procedures?

Grain-Size Composition of Soils

Sand ejecta samples from areas in Christchurch



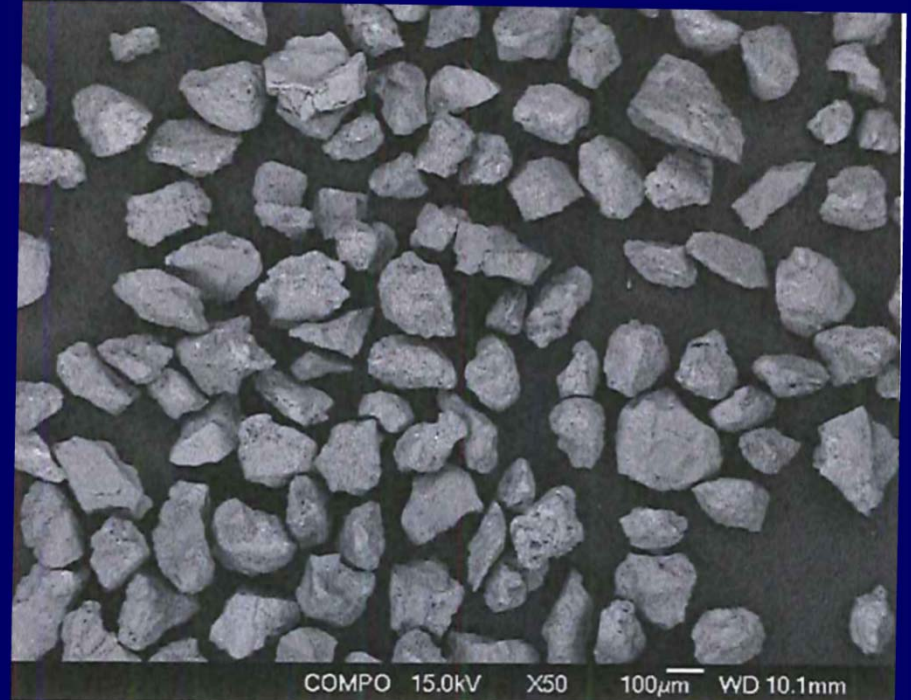
(Courtesy of M. Pender, Univ. of Auckland)

- Clean fine sands and non-plastic silty sands
- Does soil '*know*' that the #200 sieve exists?

Particle Shape of Soils

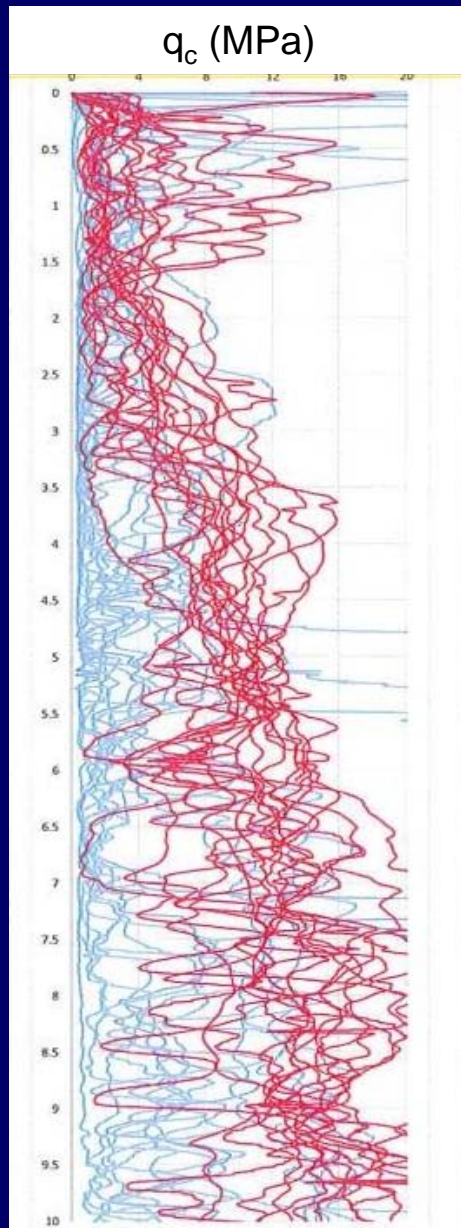


Soil sample Site 3 Natural Soil Panel 1 at -1.76m R.L at 50x magnification.

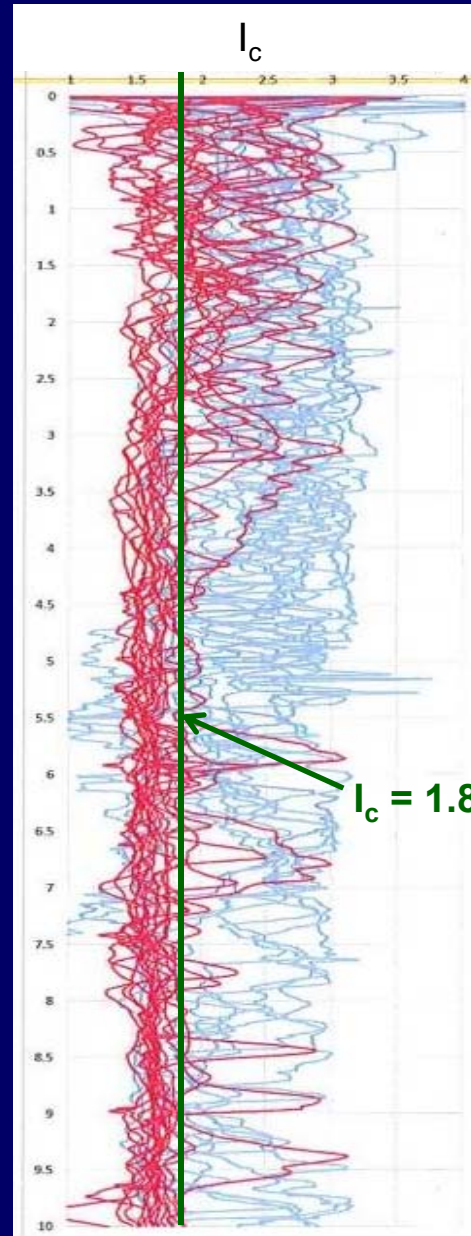


Soil sample Site 4 Natural Soil Panel 2 at -1.94m R.L at 50x magnification.

Observations of Liquefaction Ejecta



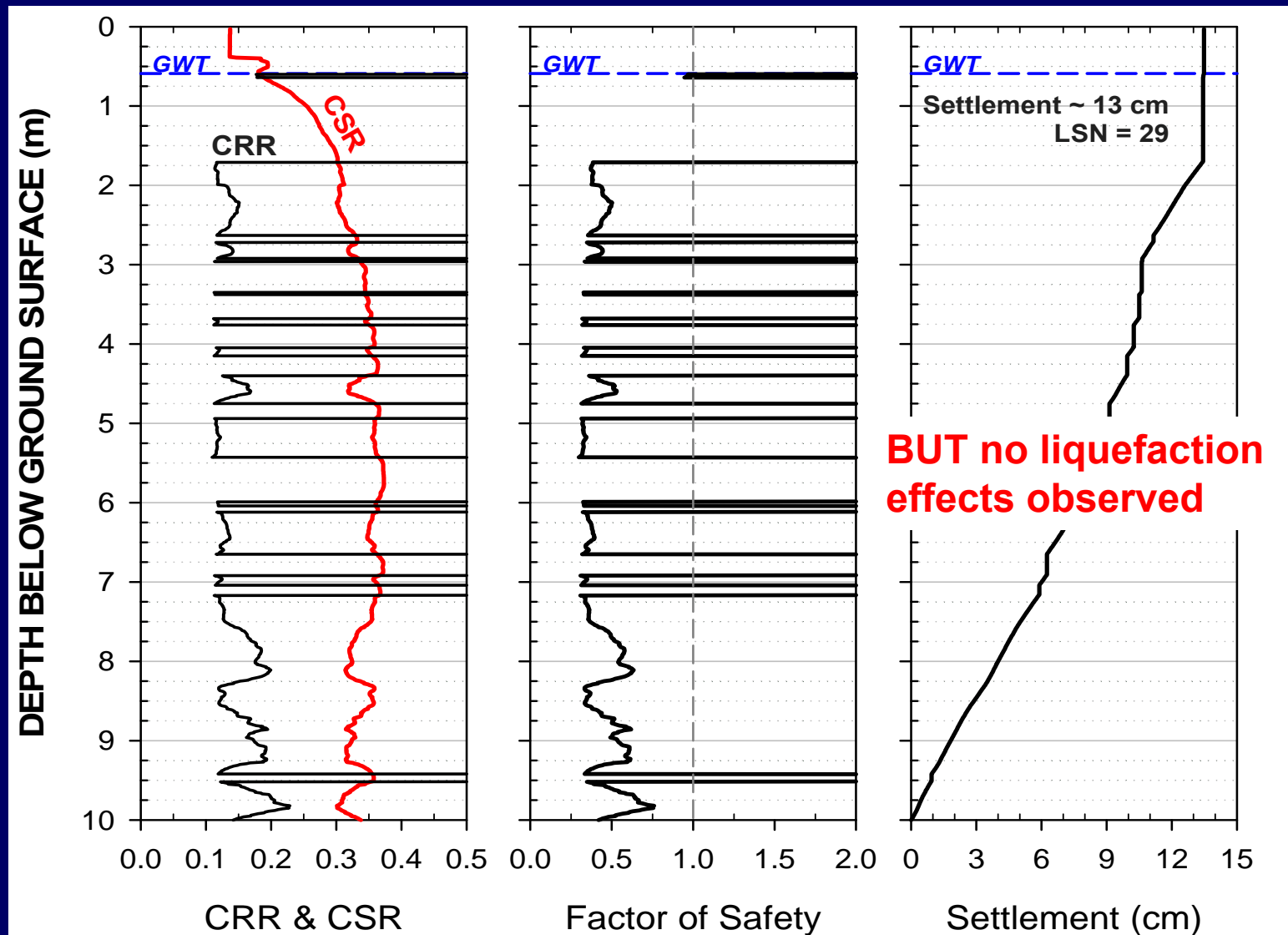
Depth (m)



2010 Darfield EQ
Ejecta Observed
No Ejecta

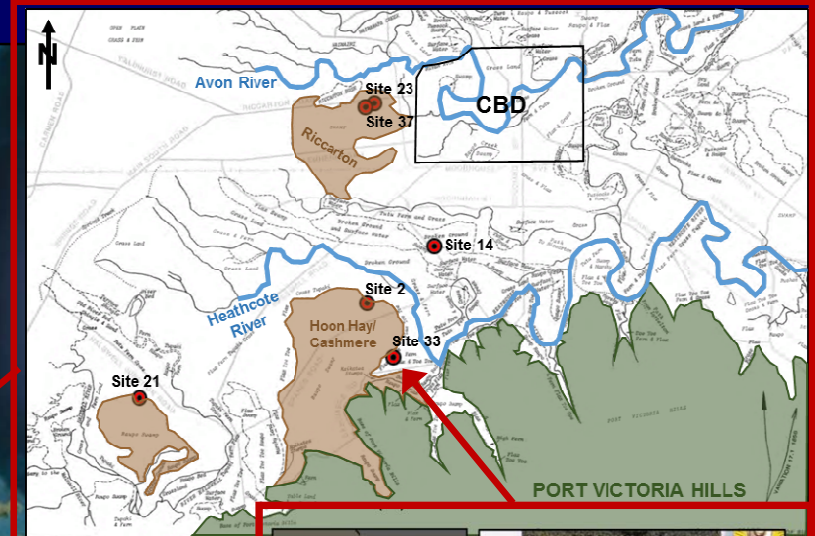
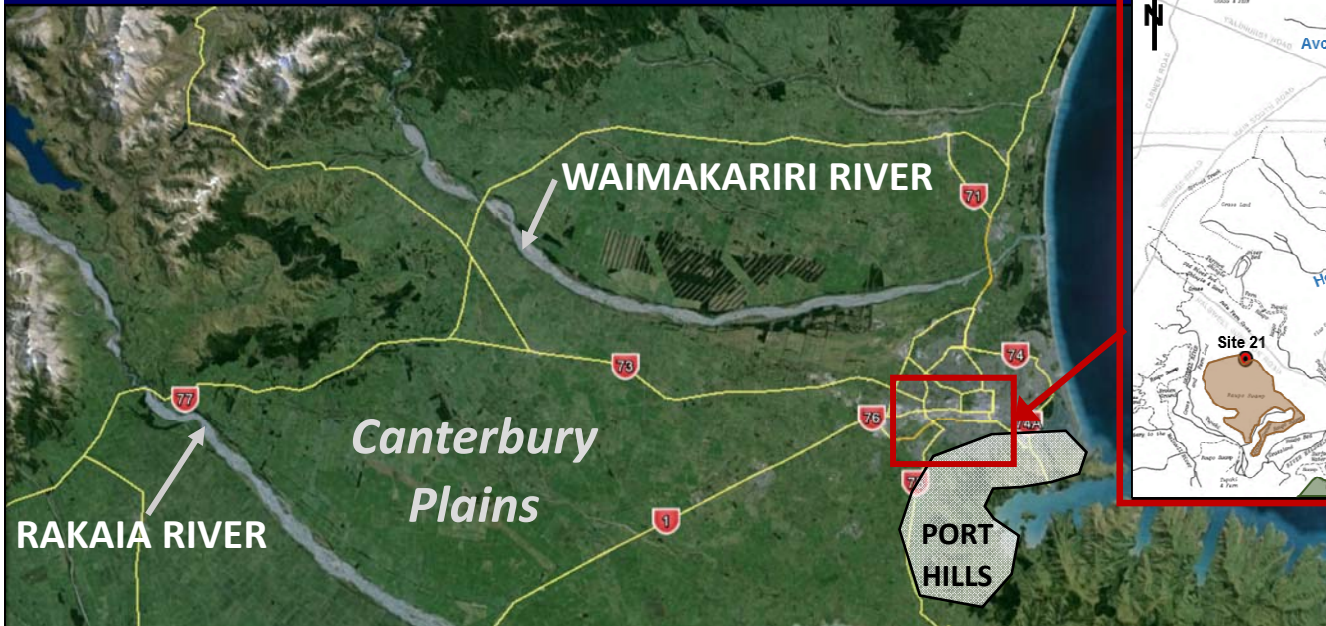
van Ballegooy et al.
Tonkin & Taylor
for the EQC

Liquefaction Assessment at Stratified Site



Riccarton Road Site 23 22 Feb 2011 EQ: $PGA = 0.37 g$, $GWT = 0.6 m$ BGS, $P_L = 50\%$, $LPI = 19$, CPT_36420
(Beyzaei et al.; CRR and FS plots exported from CLiq)

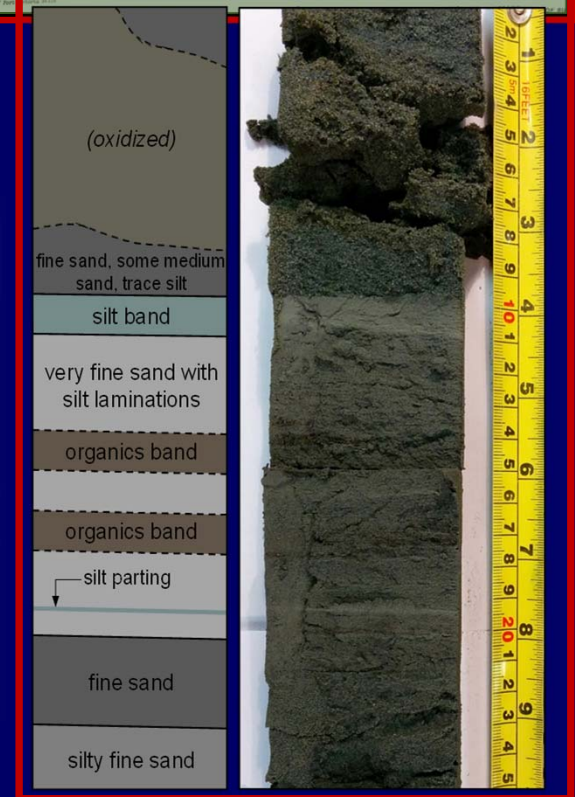
Depositional Environment (Beyzaei et al.)



1880 Photo from Christchurch: Swamp to City



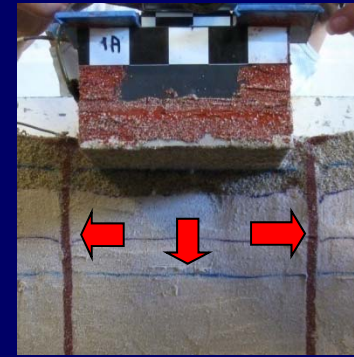
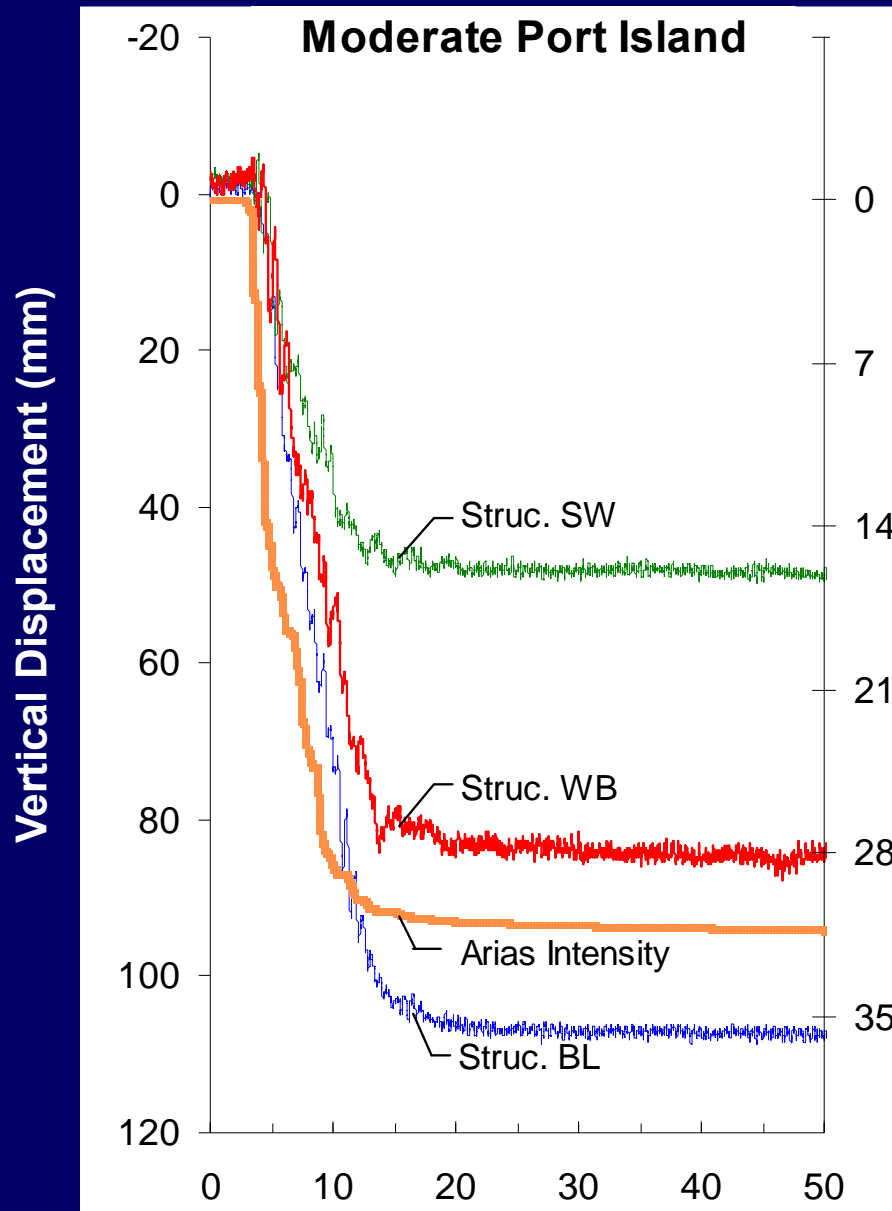
1918 Photo from Christchurch: Swamp to City



Liquefaction-Induced Building Settlement

5. What are the best paths forward for advancing understanding and procedures to address it?

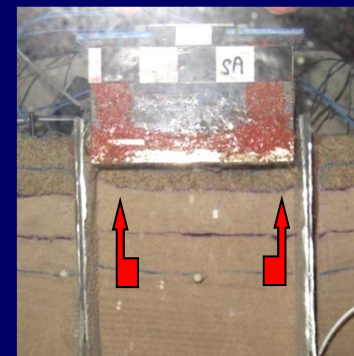
Isolation of Liquefaction Mechanisms in Centrifuge



Struc. BL
(Baseline)



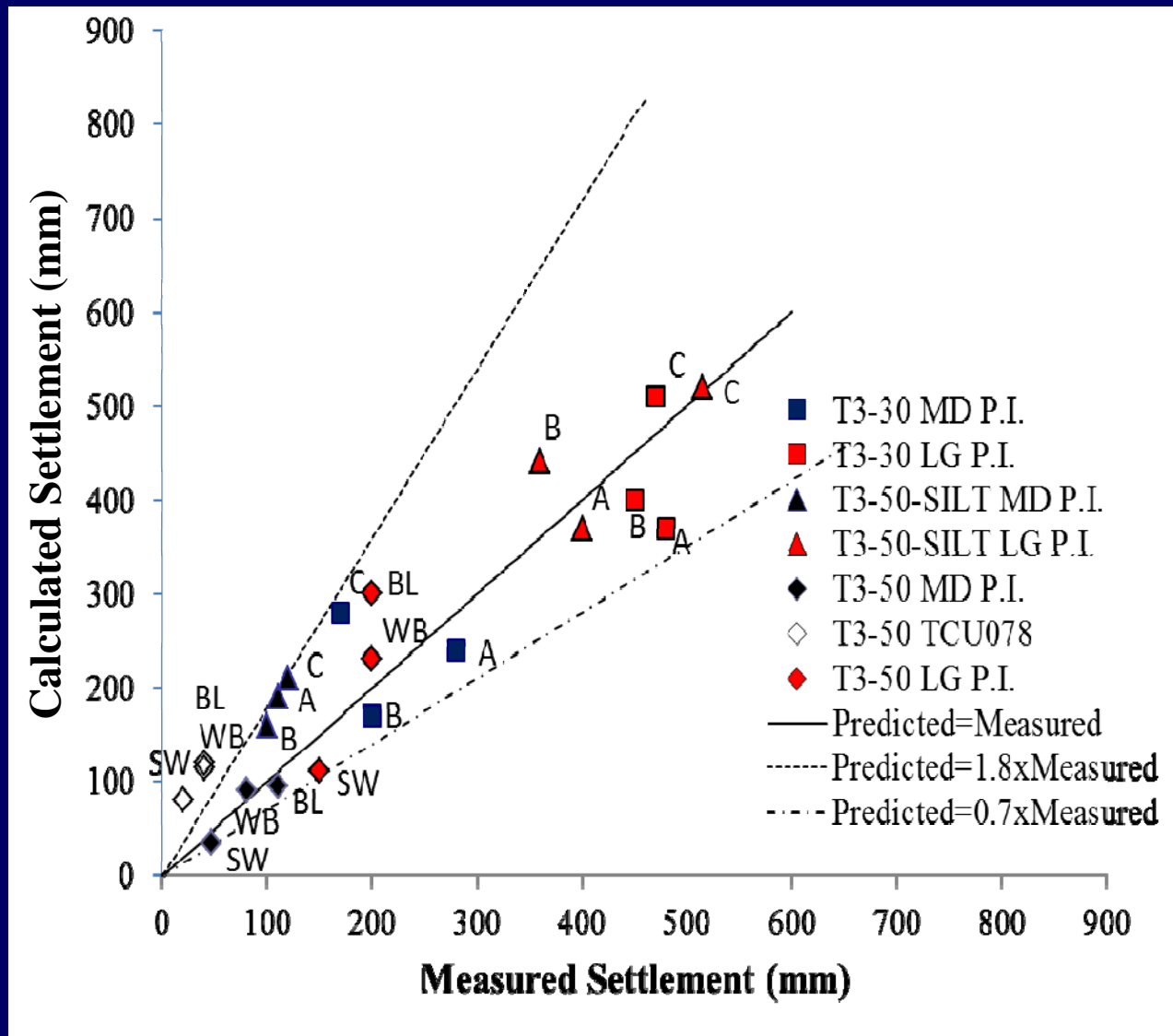
Struc. WB
(Water Barrier)



Struc. SW
(Structural Wall)

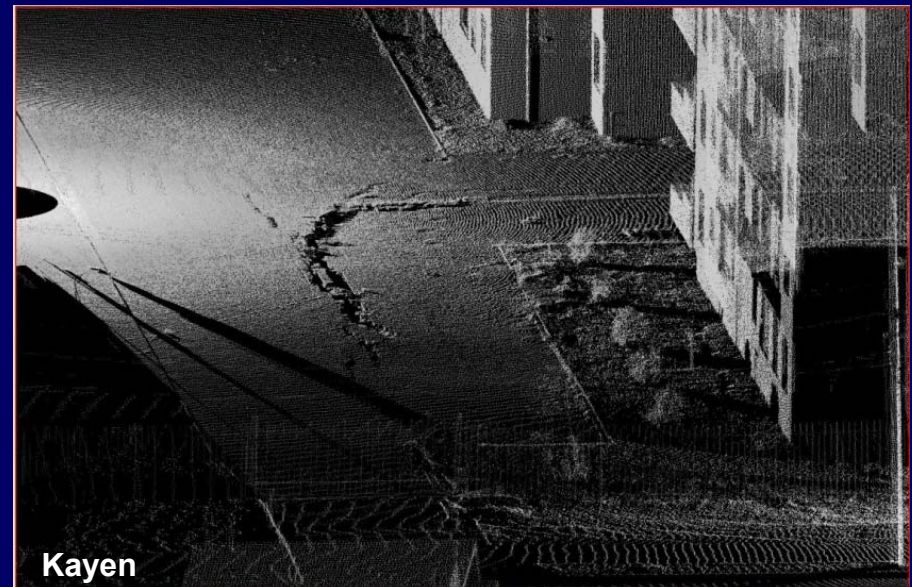
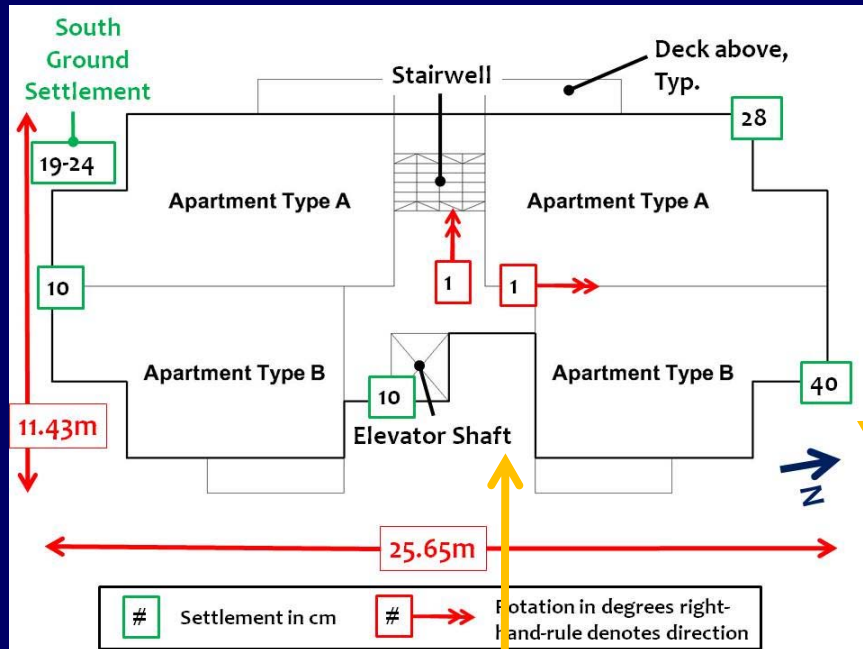
Dashti et al. 2010b

Careful Evaluation of Analytical Procedures



Foundation Settlement and Building Damage Case Histories

Bray, Arduino, Hutchinson, & Maureira



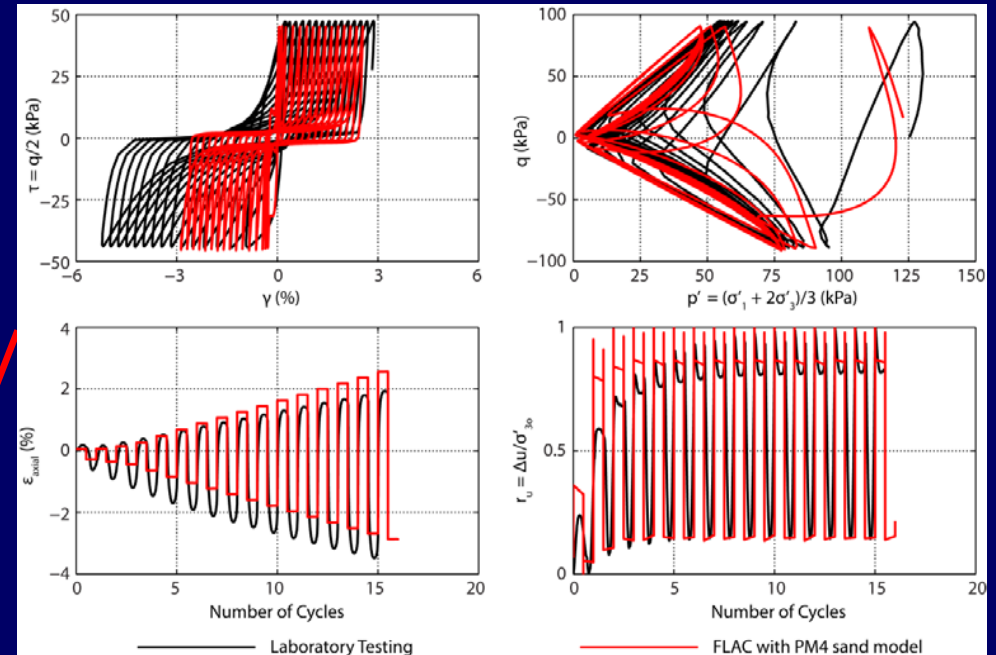
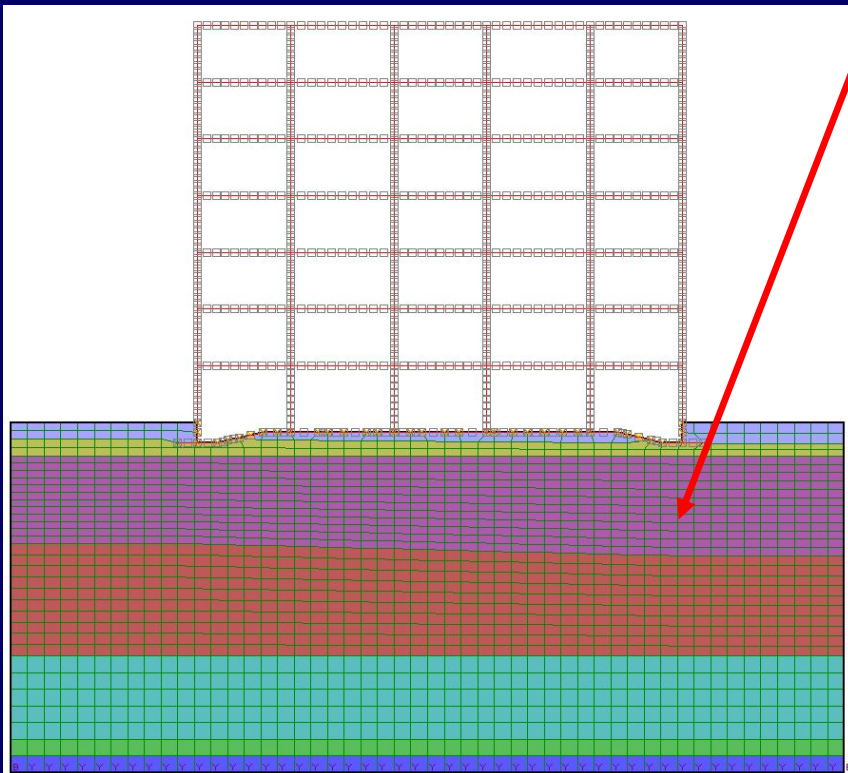
SSI Nonlinear Effective Stress Analyses

Luque & Bray (2015)

using CTX Data by Markham et al. (2015)
and *PM4Sand* by Boulanger & Ziotopoulou (2015)



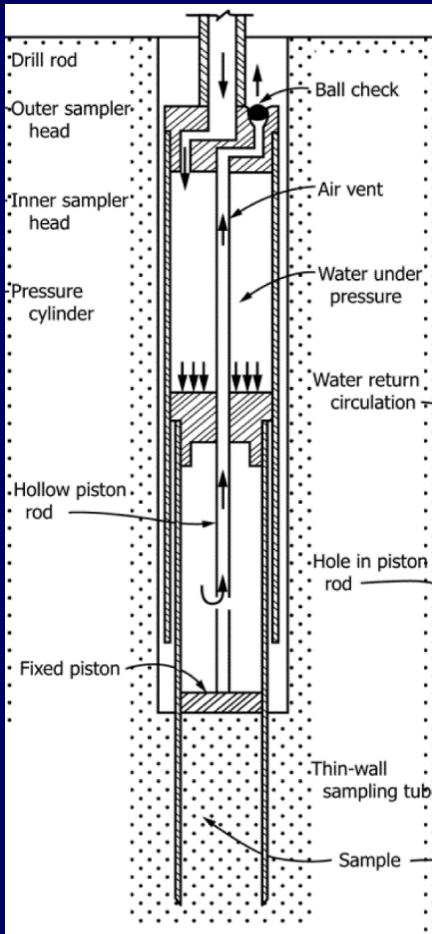
FTG-7 Building Christchurch



EQ	Calculated Differential Settlements	Measured Differential Settlements
4SEP10	0.6 to 0.7 cm	No measurements
22FEB11	2.5 to 2.8 cm	1 to 3 cm
13JUN11	2.0 to 2.2 cm	0.1 to 2.1 cm

“Undisturbed” Soil Sampling & Testing

D&M Thin-Walled Piston Sampler



ASTM D6519-08



Careful Transportation



Careful Test Preparation