Capturing the Effects of Liquefaction-Induced Ground Deformation

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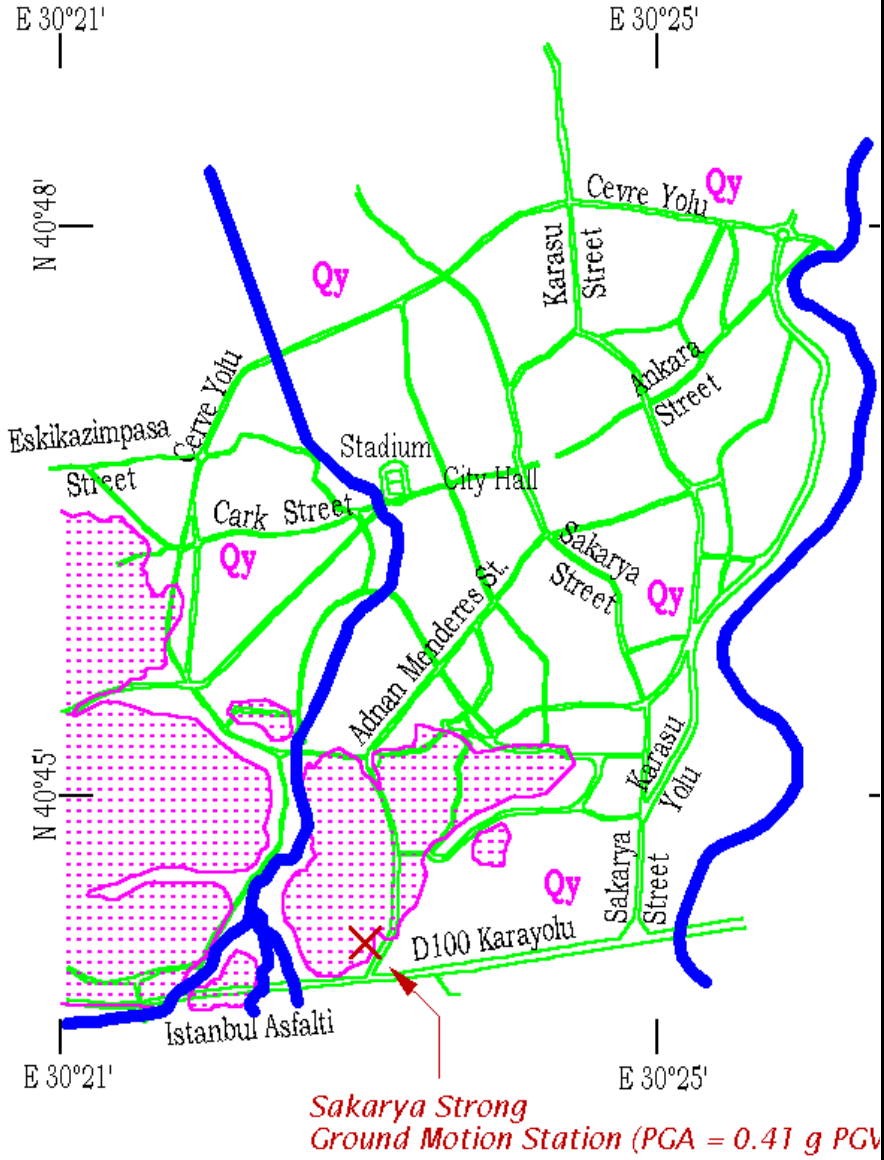
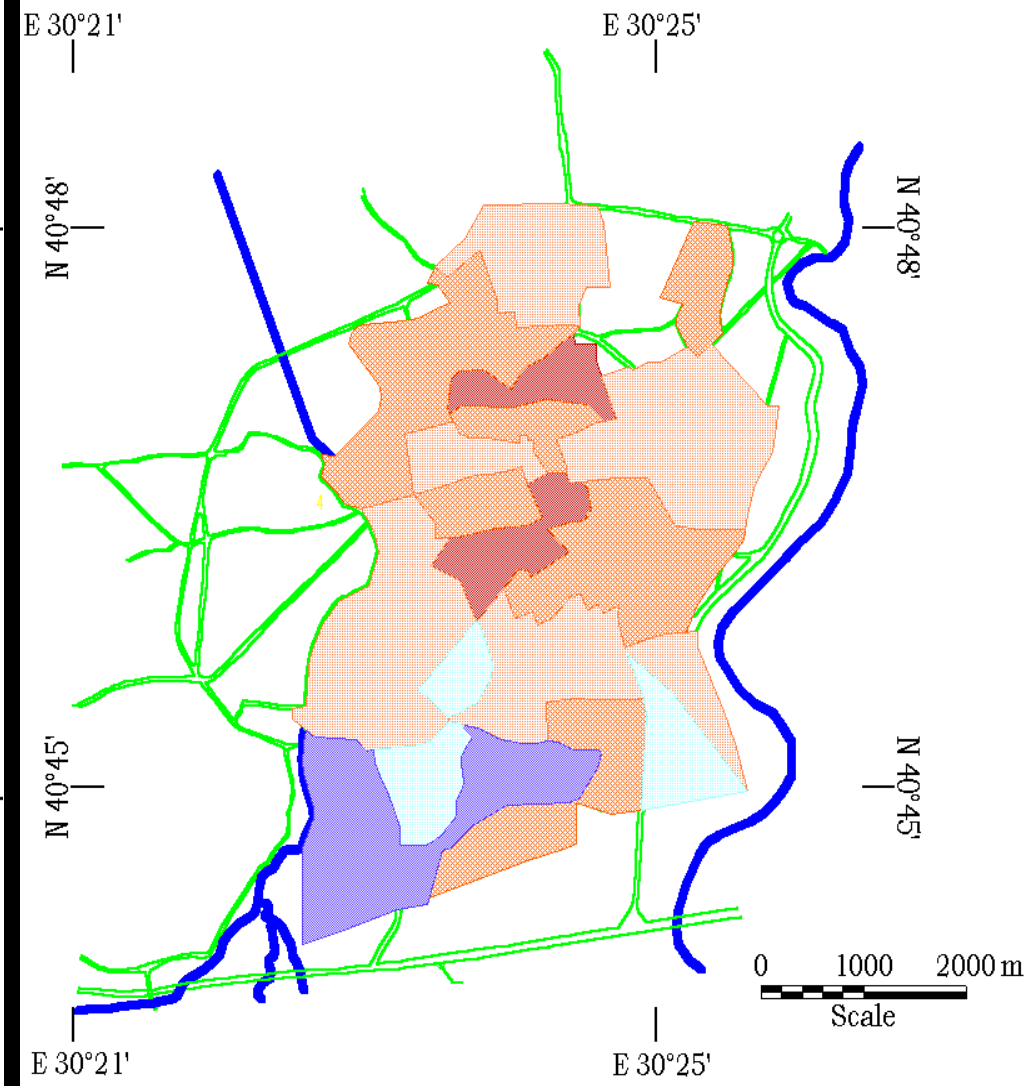
Geotechnical Extreme Events Reconnaissance
Turning Disaster into Knowledge

www.geerassociation.org

Effects of the 1999 Kocaeli Earthquake: Adapazari



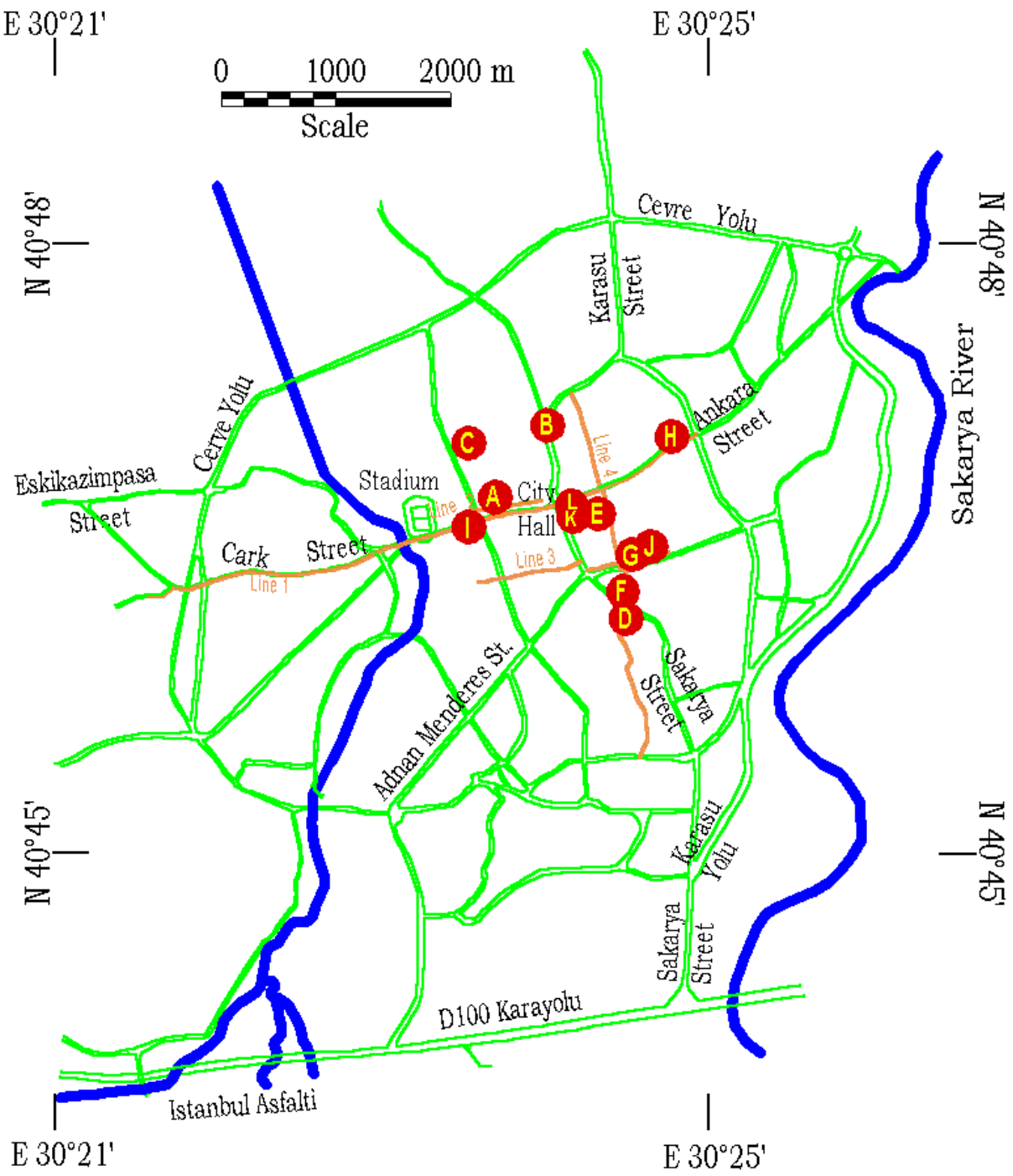


Adapazari

ADAPAZARI DAMAGE STATISTICS

% Heavily damaged buildings by district

- Fewer than 5%
- 5 to 15%
- 15 to 30%
- 30 to 45%
- More than 45%



City of Adapazari

Post-EQs Surveys

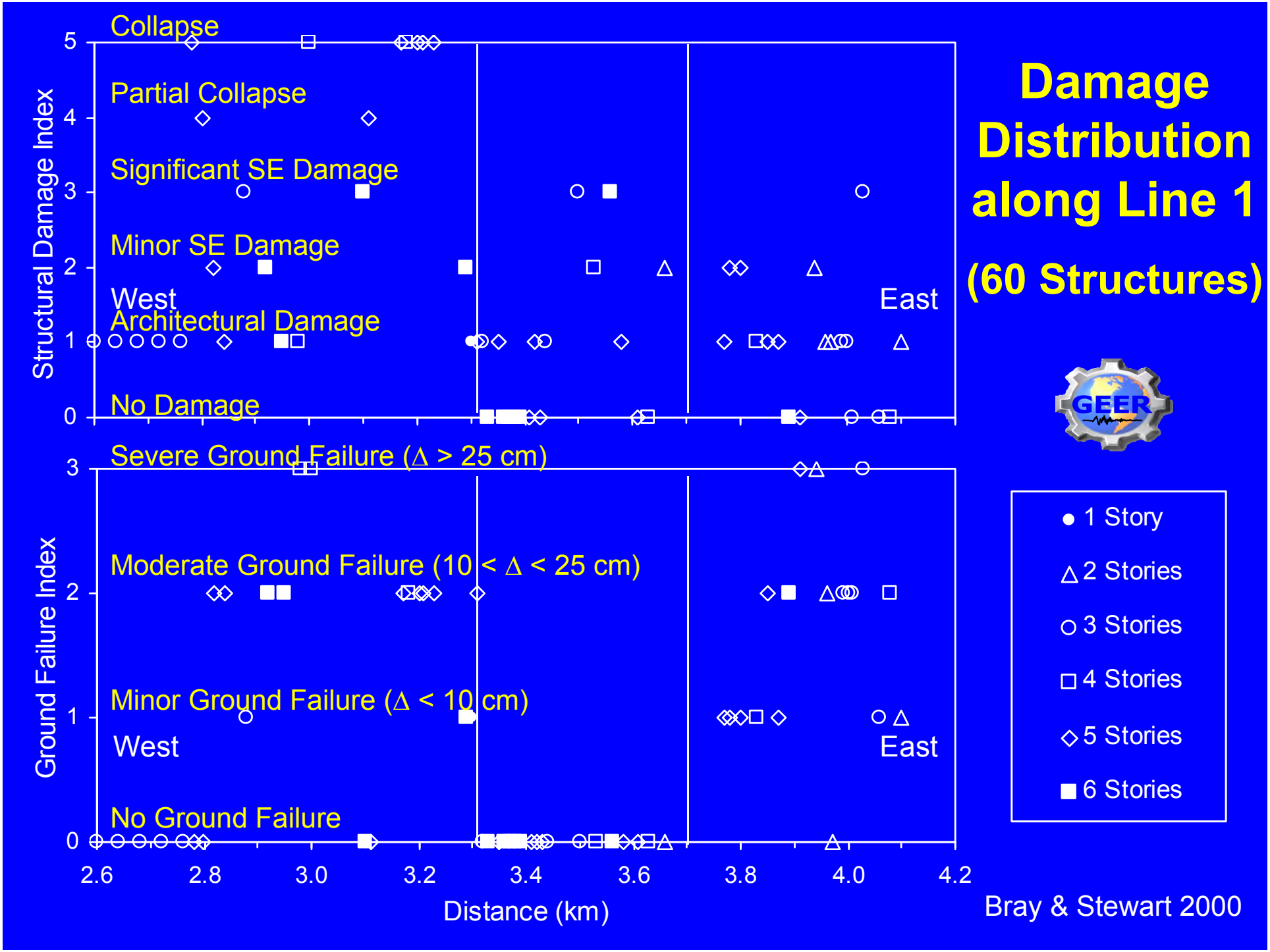
Rapid Field Survey Procedures

Structural Damage Index (modified from Coburn and Spence, 1992)

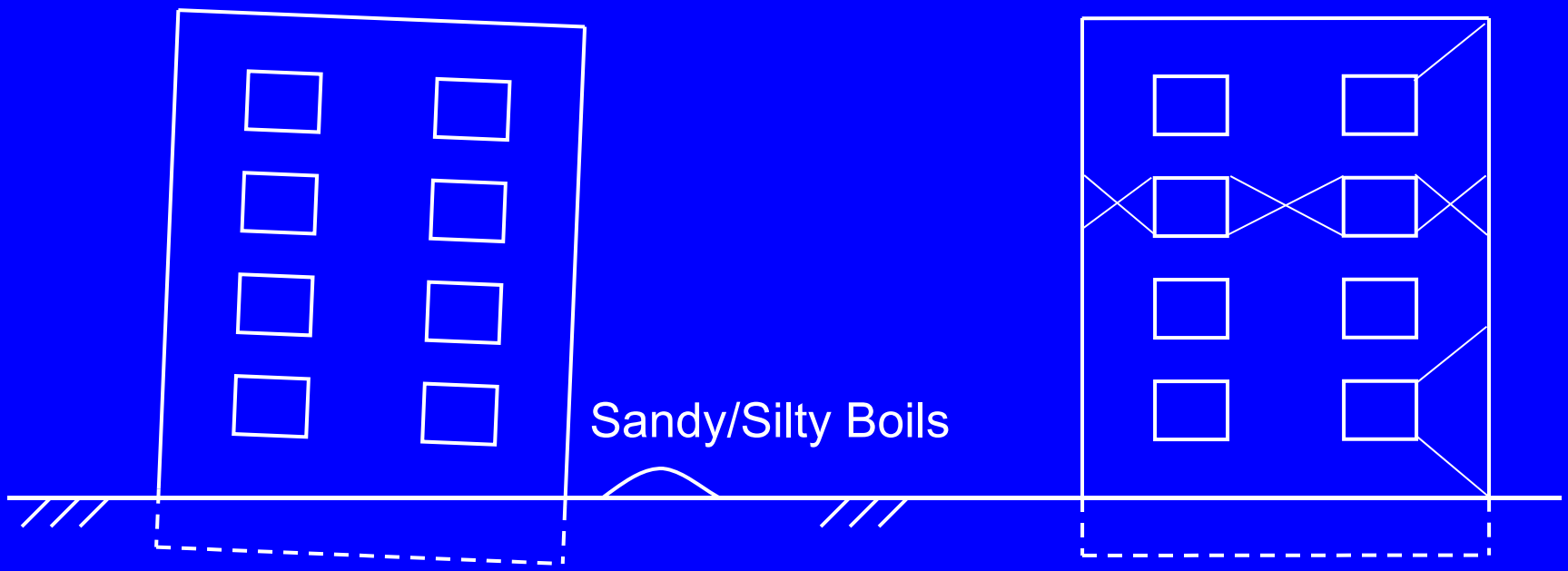
Index	Description	Interpretation
D0	No Observable Damage	No cracking, broken glass, or architectural damage, etc.
D1	Light Damage	Cosmetic cracking, no observable distress to load bearing structural elements
D2	Moderate Damage	Cracking in load bearing elements, but no significant displacements across these cracks
D3	Heavy Damage	Cracking in load bearing elements with significant deformations across the cracks
D4	Partial Collapse	Collapse of a portion of the building in plan view (i.e., a corner, or a wing of building)
D5	Collapse	Collapse of the complete structure or loss of a floor of the structure

Ground Failure Index (after Bray and Stewart, 2000)

Index	Description	Interpretation
GF0	No Observable Ground Failure	No settlement, tilt, lateral movement, or sediment ejecta
GF1	Minor Ground Failure	Settlement, Δ < 10 cm; Tilt < 1 degree; no lateral movements
GF2	Moderate Ground Failure	10 cm < Δ < 25 cm; Tilt of 1-3 degrees; small lateral movements (< 10 cm)
GF3	Significant Ground Failure	Δ > 25 cm; Tilt of > 3 degrees; Lateral movement > 25 cm


Collapse
Partial Collapse
Significant SE Damage
Minor SE Damage
West
East
Architectural Damage
No Damage
Structural Damage Index
Severe Ground Failure (Δ > 25 cm)
Moderate Ground Failure (10 < Δ < 25 cm)
Minor Ground Failure (Δ < 10 cm)
West
East
No Ground Failure
Ground Failure Index
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
Distance (km)
Damage Distribution along Line 1
(60 Structures)
GEER
1 Story
2 Stories
3 Stories
4 Stories
5 Stories
6 Stories
Bray & Stewart 2000

Observations of ground failure **&** **Surveys of building damage**



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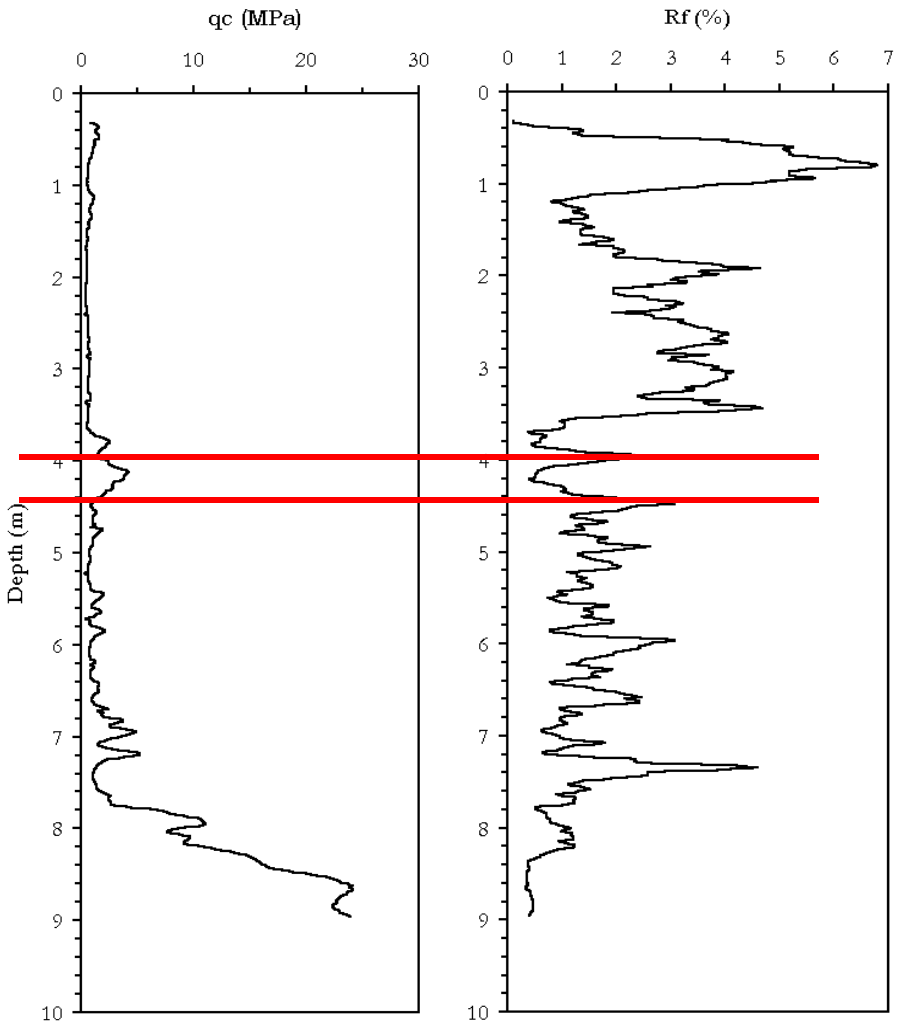
Unknown Depth, Thickness, Characteristics, and Lateral Extent of Subsurface Soils

Fieldwork in Adapazari (Bray et al. 2004)

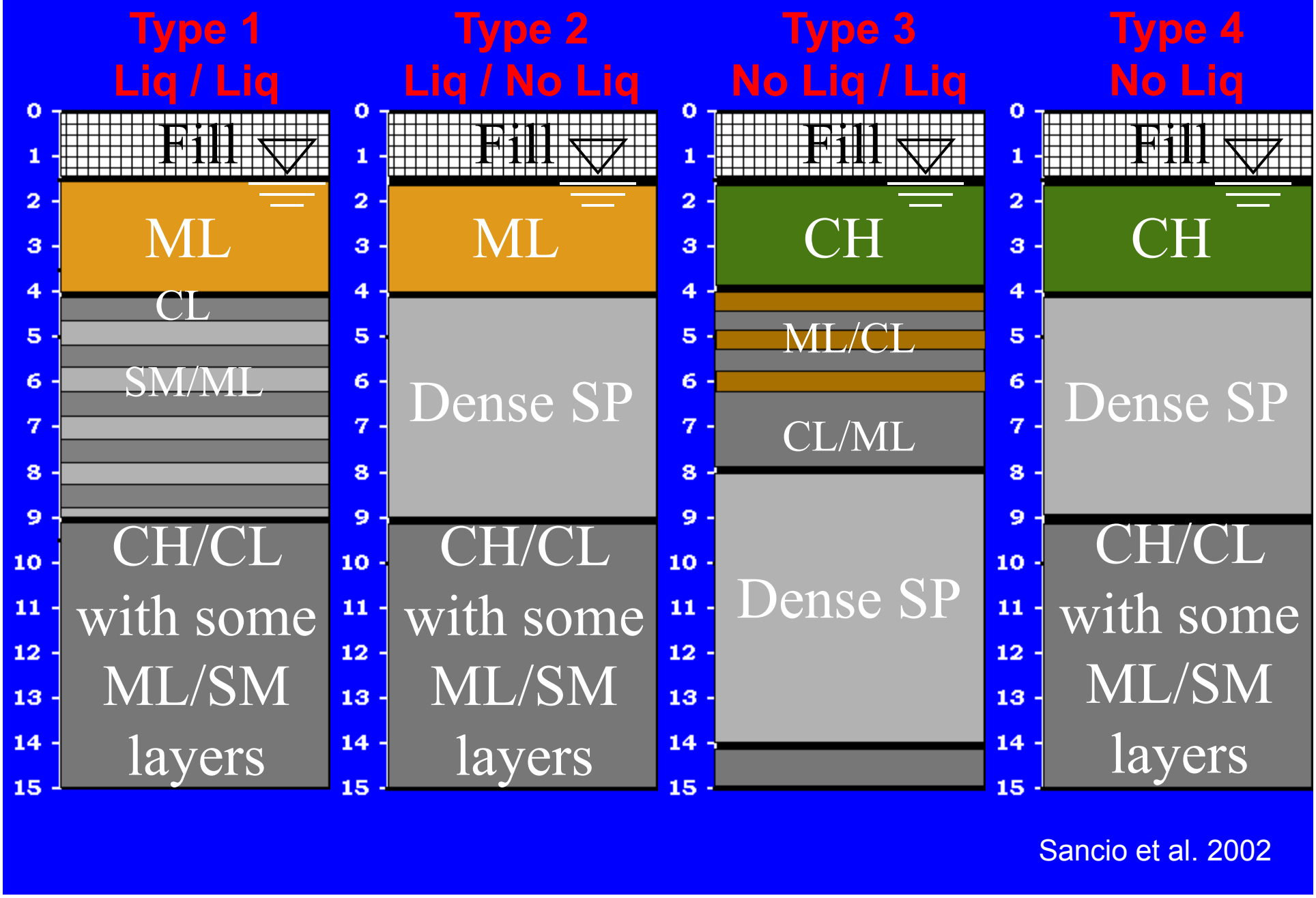


Depth Scale (m)	Lithology	USCS	Sample Type and No.	Recovery / Length (cm)	SPT Blows / 15 cm	Casing Depth (m)	Rod Length (m)	Energy Ratio (%)	Description
									ASPH: Asphalt of Yakin Street.
									Fill
		ML/CL	S-A2-1	28/45	1-2-1	-	2.60	37	ML: Brown clayey silt to silty clay with some red oxidation points and some fine sand
		ML	S-A2-2	42/45	1-2-2	-	4.13	53	
		CH/MH	SH-A2-3	42/42		2.55	-	-	CH: Brown high plasticity silty clay to clayey silt. Some fine to medium sand in a silty clay matrix was observed in the wash water
		CL/CH	S-A2-4	40/45	2-1-1	3.35	5.65	52	
		ML	S-A2-5	28/45	2-3-4	4.15	5.65	65	ML: Brown/gray clayey silt with traces of fine sand
		CL	SH-A2-6	42/42		4.95	-	-	CH: Gray silty clay of medium to high plasticity. Sticky to the fingers. Softens when remoulded
		MH/CH	S-A2-7	39/45	1-1-2	5.95	7.17	65	
		ML	S-A2-8	32/45	3-5-5	6.95	8.70	60	ML: Gray clayey silt with some fine sand
		SP-SM	S-A2-9	38/45	12-20-16	8.45	10.22	61	SP-SM: Poorly graded gray fine sand with silt. Gravel content ~ 8% in sample S-A2-10
		SP-SM	S-A2-10	38/45	7-10-15	9.95	11.45	-	

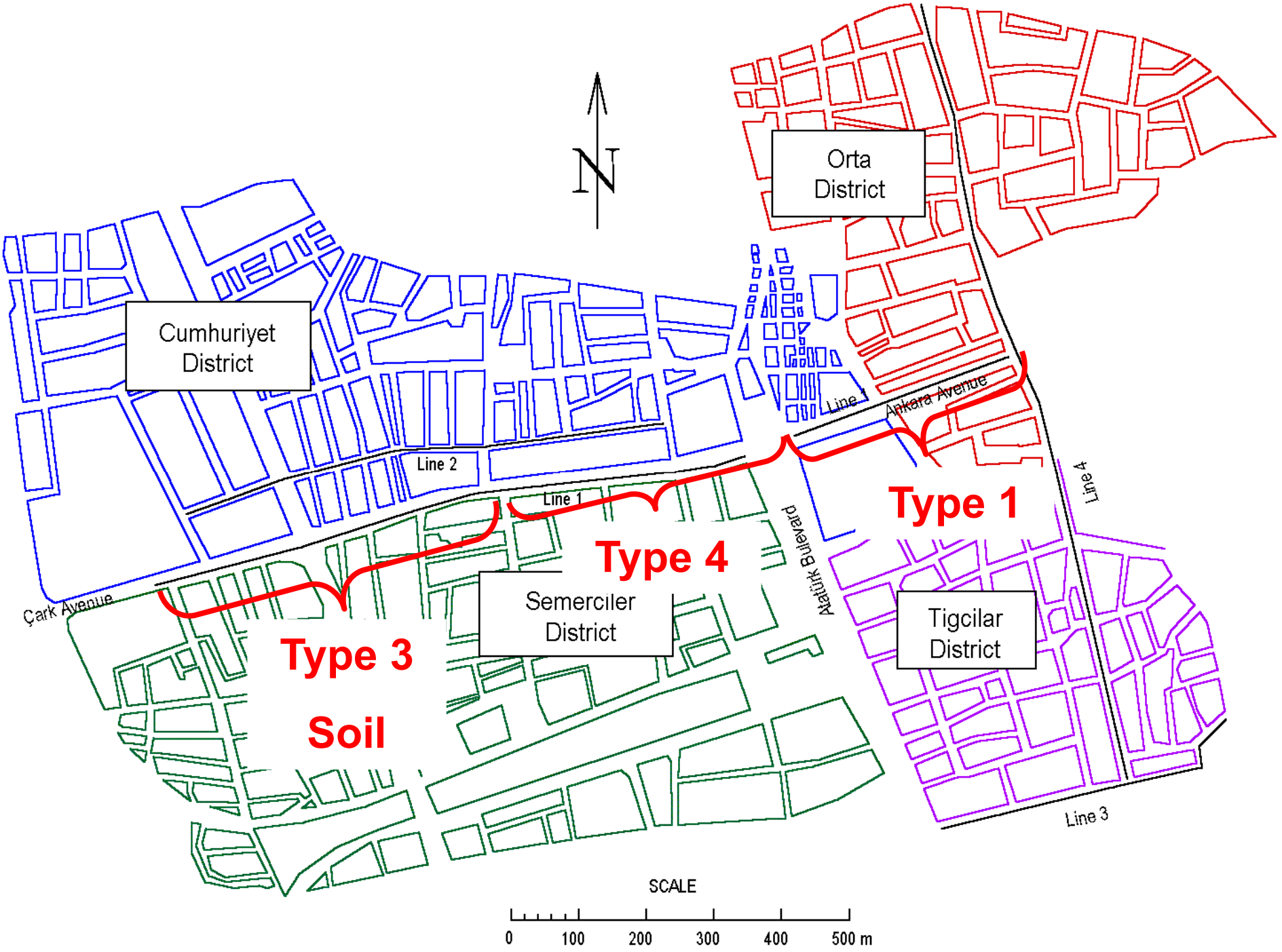
166 CPT/SCPTu & 61 BORINGS with SPT

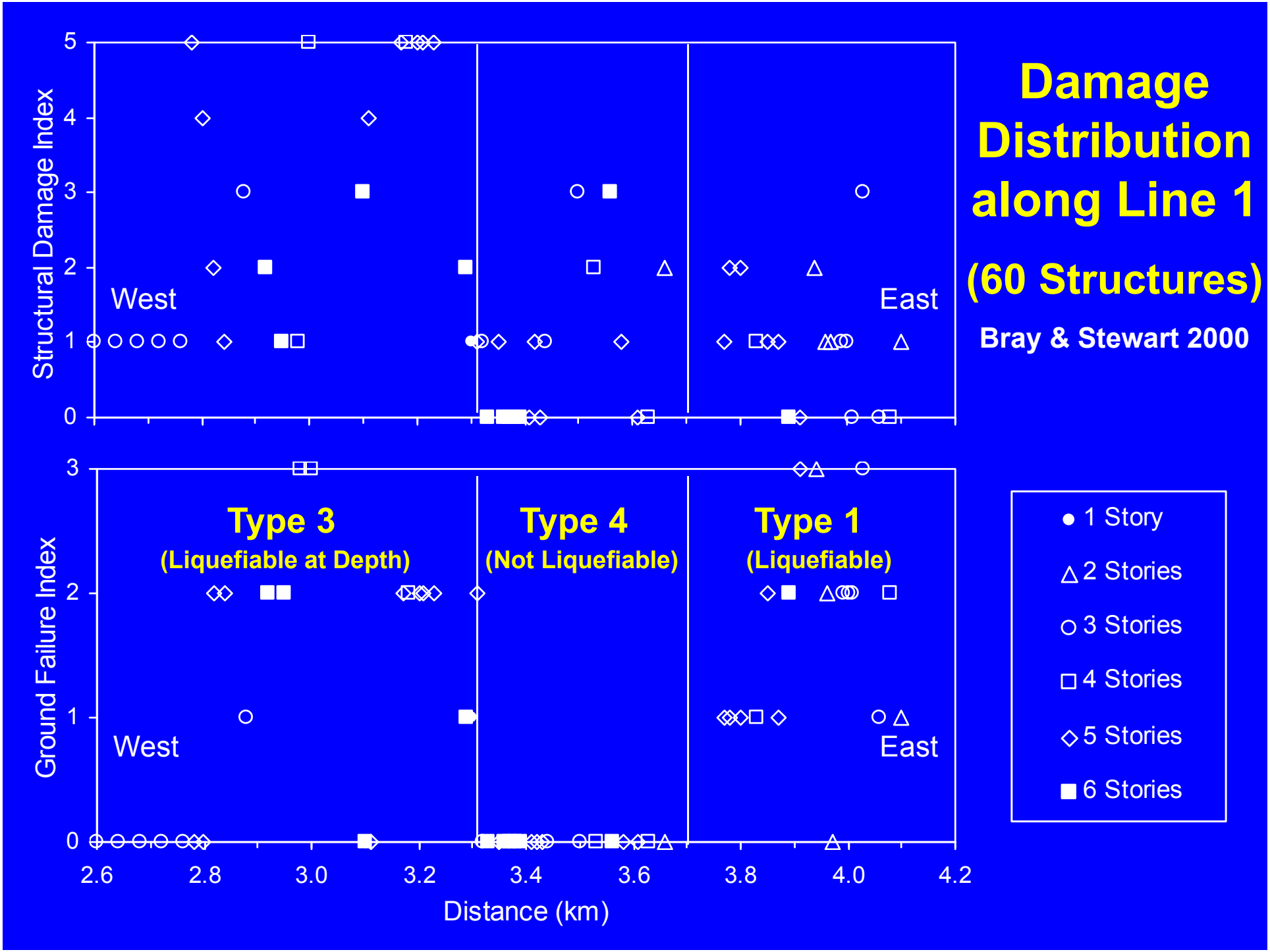
< http://peer.berkeley.edu/turkey/adapazari >

Generalized Soil Profiles of Adapazari



Sancio et al. 2002


N
Orta
District
Cumhuriyet
District
Semerciler
District
Tigcilar
District
Line 1
Ankara Avenue
Line 2
Line 1
Çark Avenue
Atatürk Boulevard
Line 4
Line 3
Type 1
Type 4
Type 3
Soil
SCALE
0
100
200
300
400
500 m

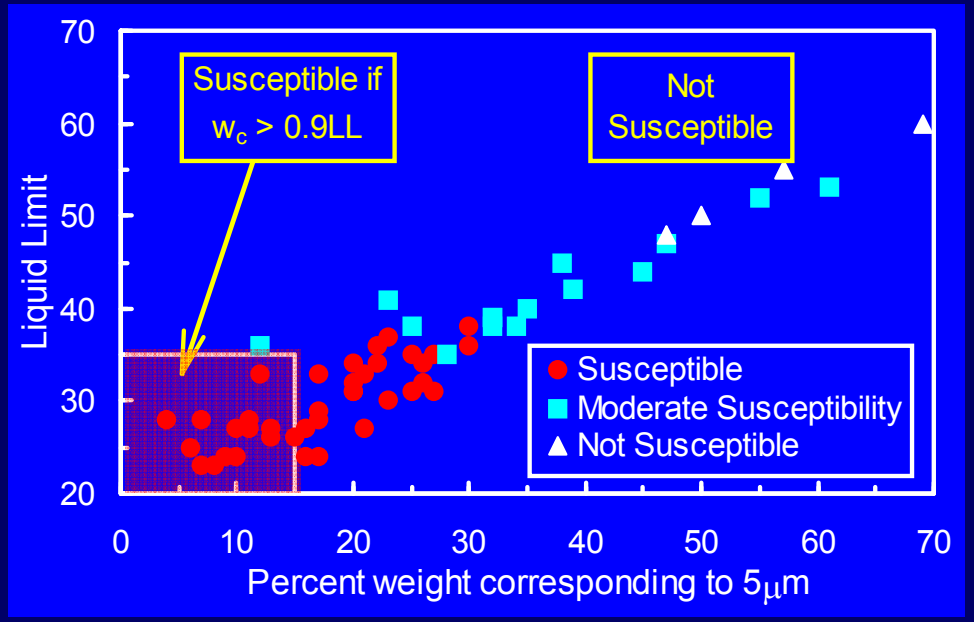

Damage Distribution along Line 1
(60 Structures)
Bray & Stewart 2000
Structural Damage Index
Ground Failure Index
West
East
Type 3
(Liquefiable at Depth)
Type 4
(Not Liquefiable)
Type 1
(Liquefiable)
1 Story
2 Stories
3 Stories
4 Stories
5 Stories
6 Stories
Distance (km)
0
1
2
3
4
5
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2

New Liquefaction Susceptibility Criteria

Chinese Criteria

(Seed and Idriss 1982

in Youd et al. 2001)



PI & w_c/LL Criteria

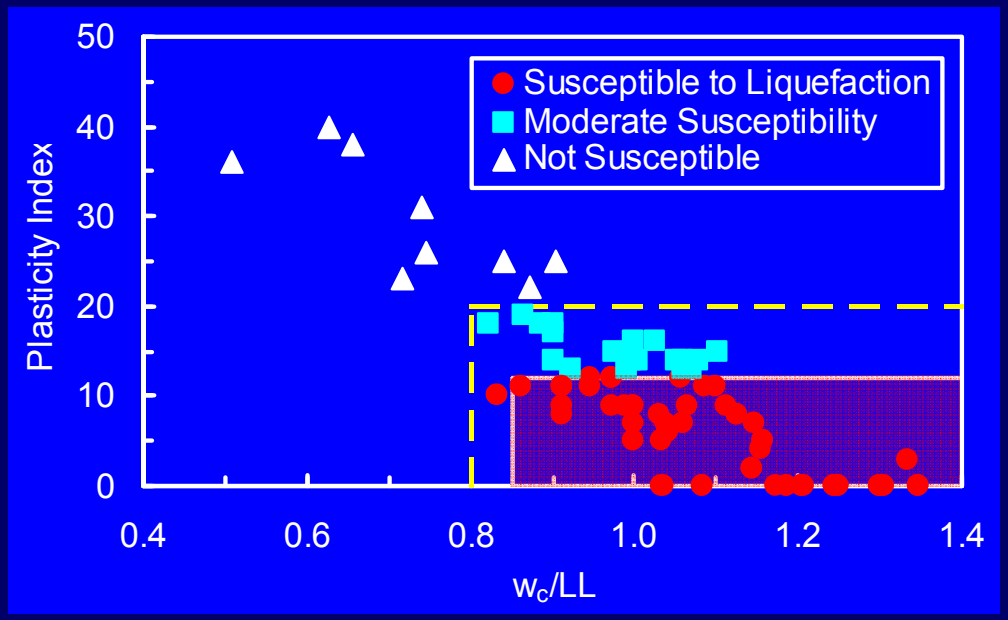
(Bray & Sancio 2006)

Susceptible:

PI ≤ 12 & w_c/LL ≥ 0.85

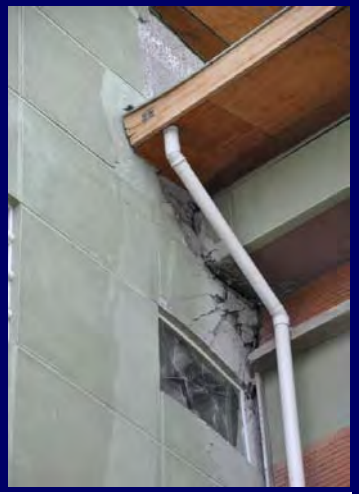
Moderate Susceptibility:

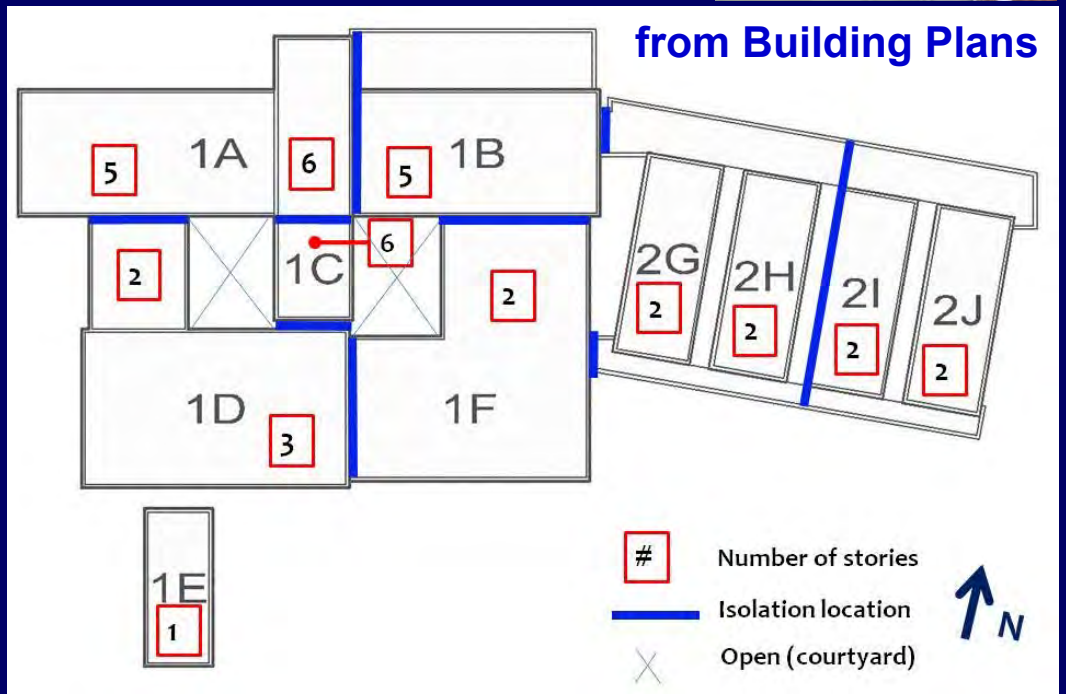
w_c/LL > 0.8 & 12 < PI ≤ 20



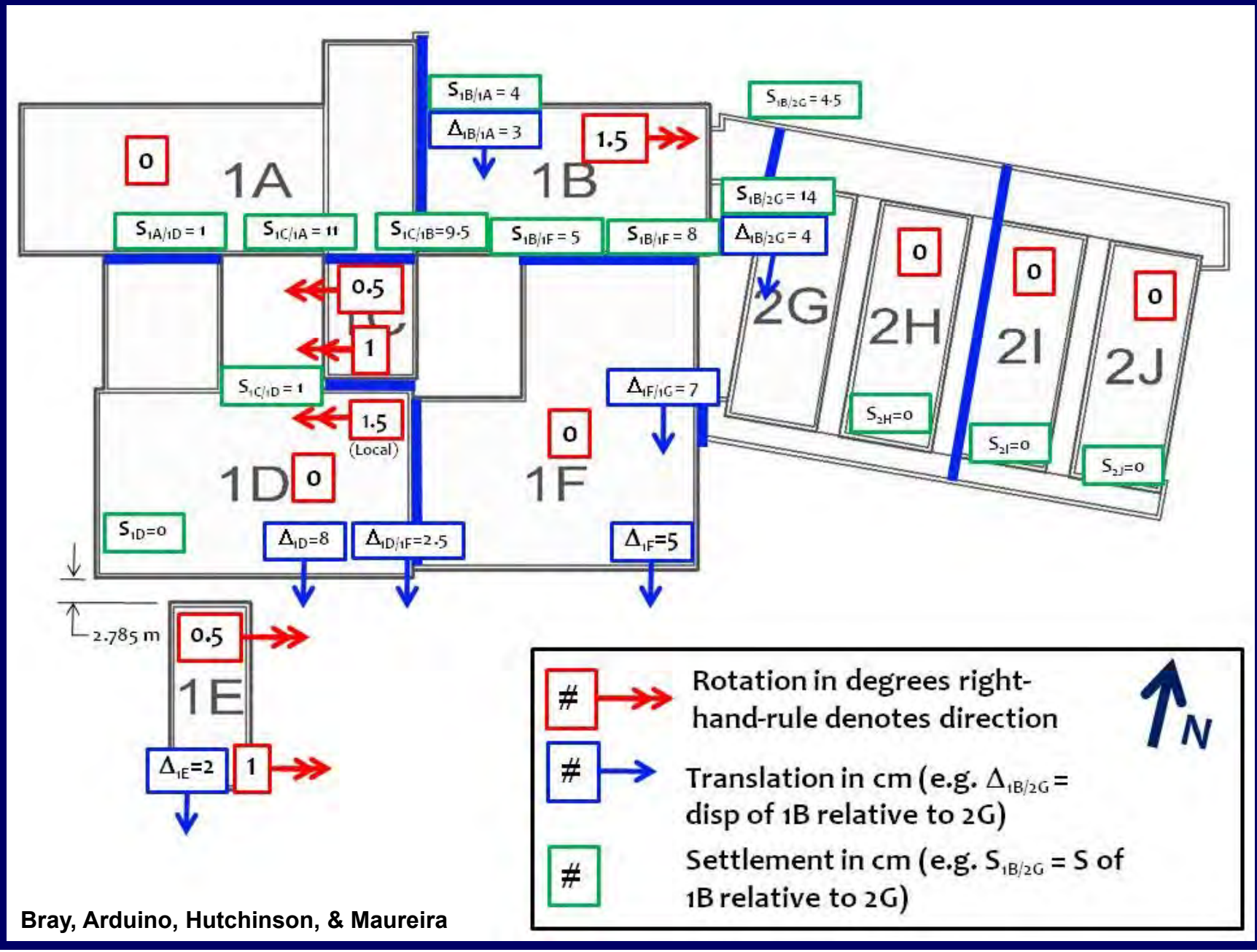
Effects of Ground Failure on Buildings – 2010 Chile EQ (M_w= 8.8)

Hospital in Curanilahue





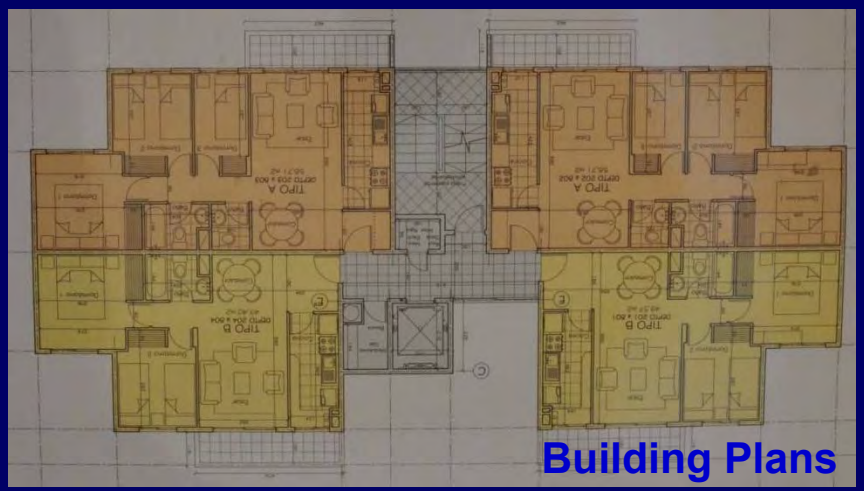
Building Displacement Measurements



Bray, Arduino, Hutchinson, & Maureira

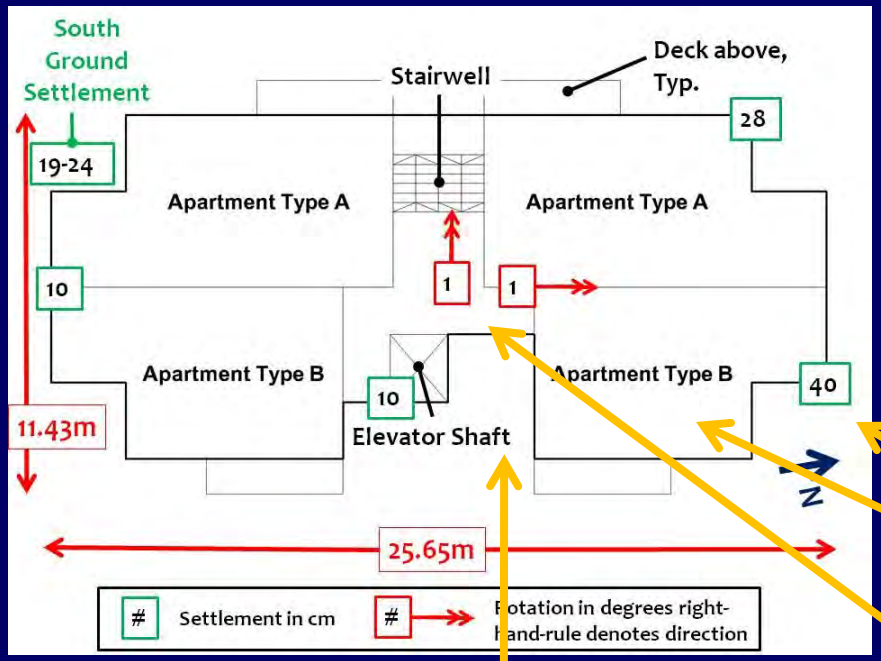
Effects of Ground Failure on Buildings – 2010 Chile EQ

Four 8-Story Condominiums, Concepcion



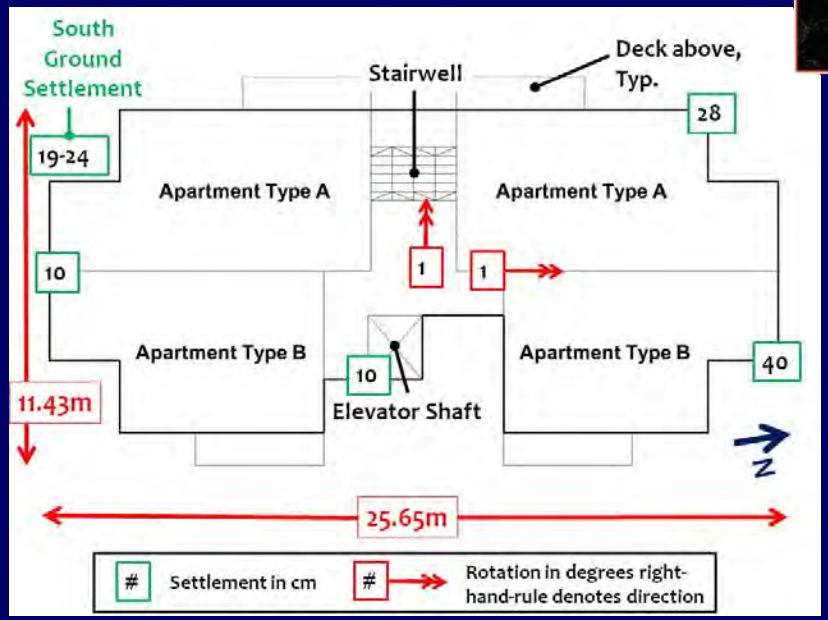
Foundation Settlement and Building Damage

Bray, Arduino, Hutchinson, & Maureira



Foundation Settlement and Building Damage

Kayen



Bray, Arduino, Hutchinson, & Maureira

Liquefaction-Induced Building Movements

2011 Tohoku, Japan EQ (M_w = 9.0)

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

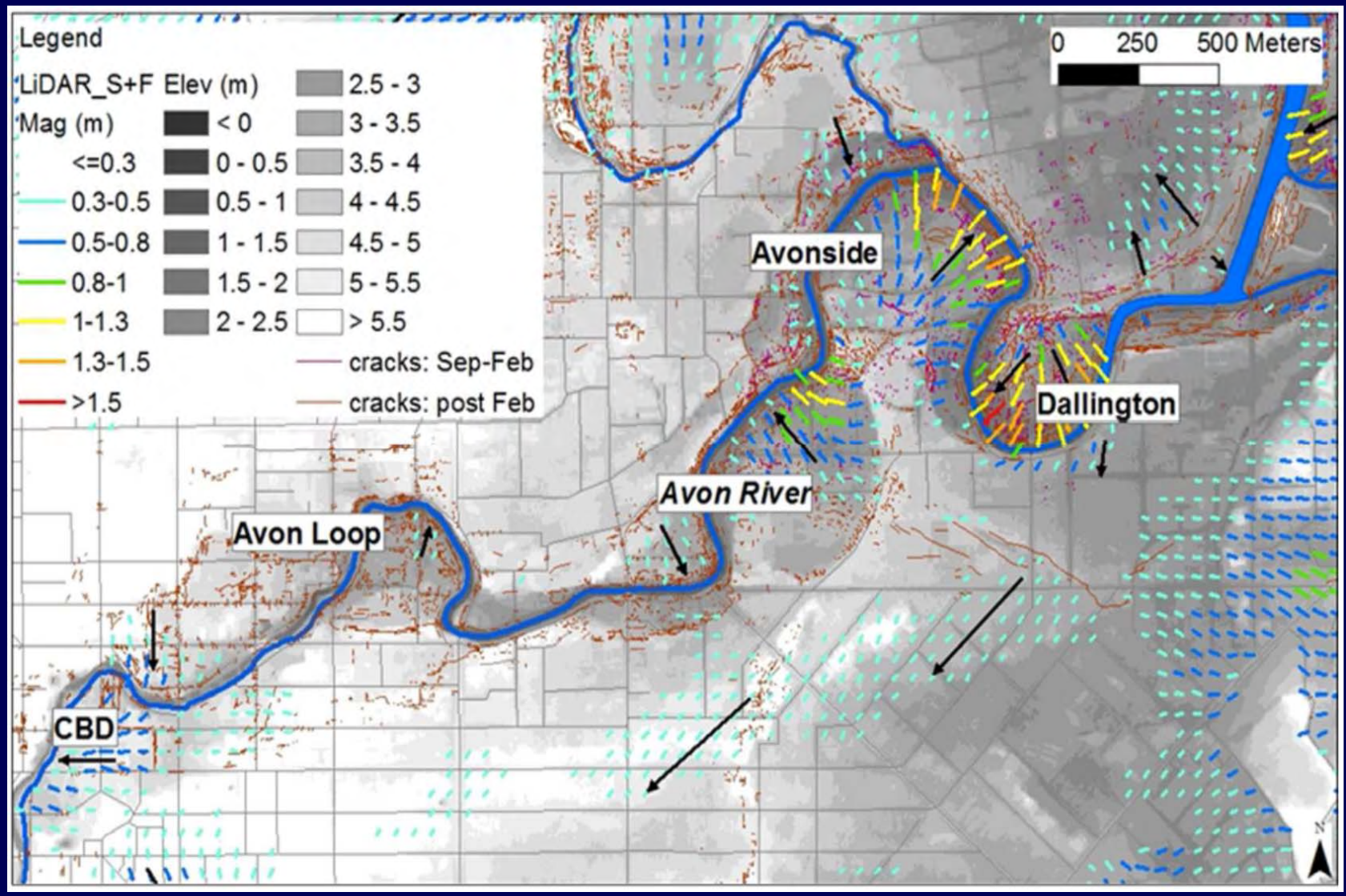
2010-11 Canterbury EQs: Widespread Liquefaction

Cubrinovski, Bray, Green, O'Rourke, Zupan, Taylor, Bradley et al.

Liquefaction Effects in Christchurch

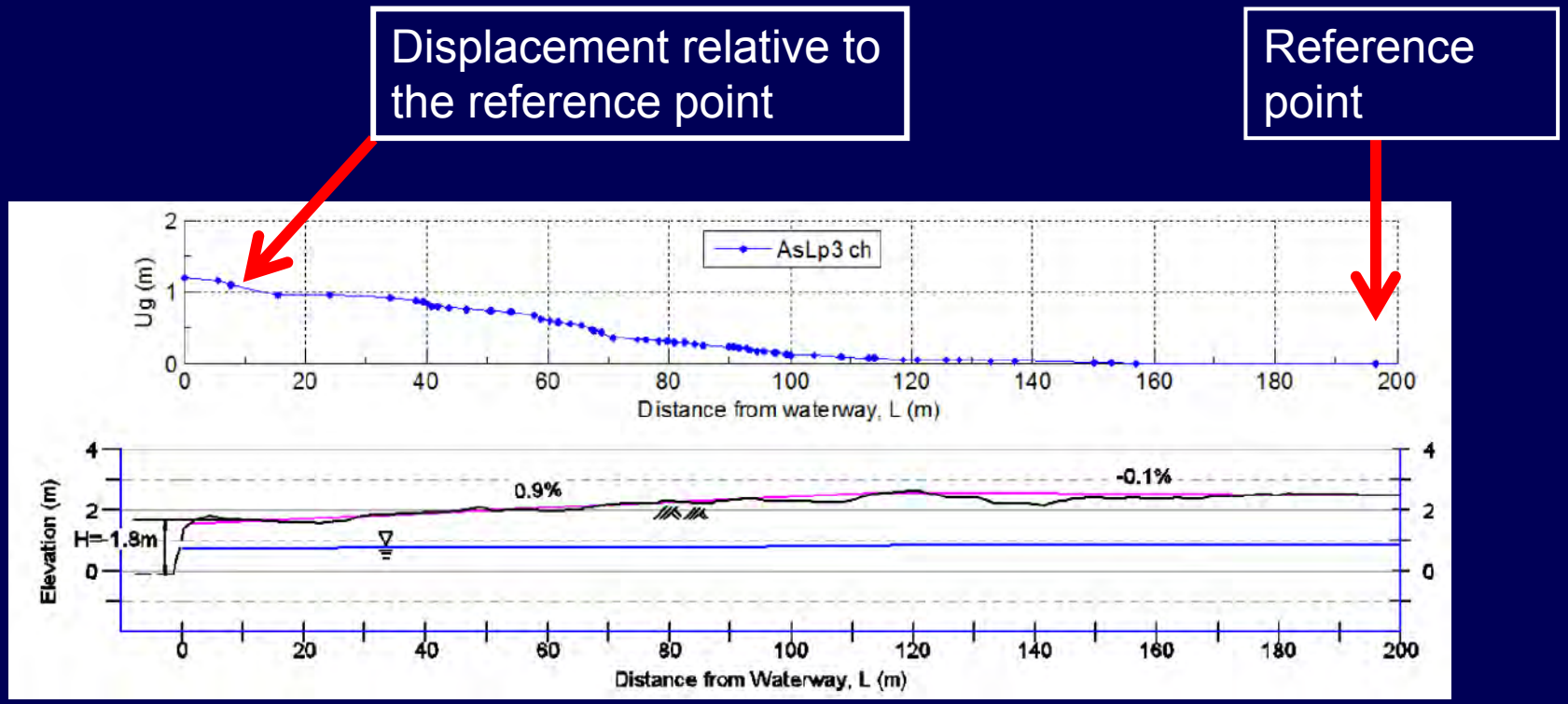
From M. Cubrinovski

Permanent Ground Displacements (LiDAR)



Cubrinovski et al.

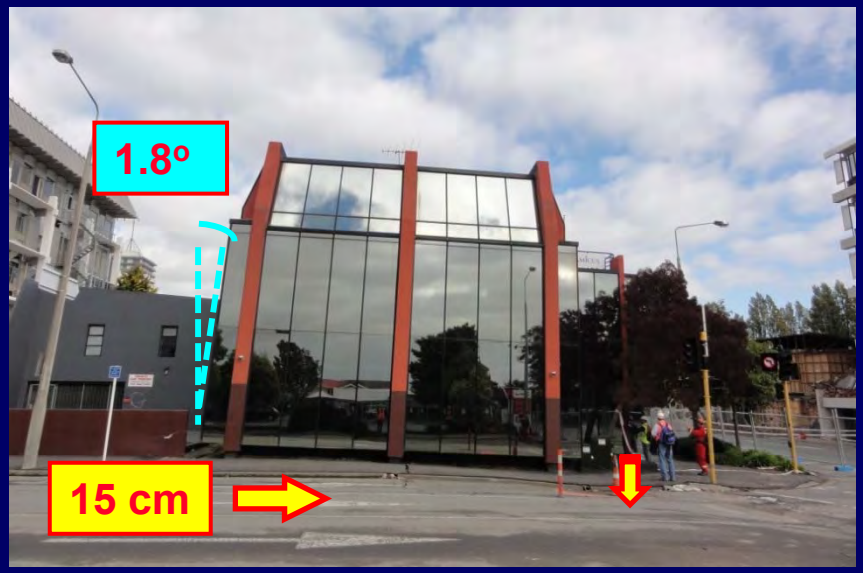
Ground Surveying Measurements (GSM)



Captures details of local spreading features within 150 m (200 m) from the river.

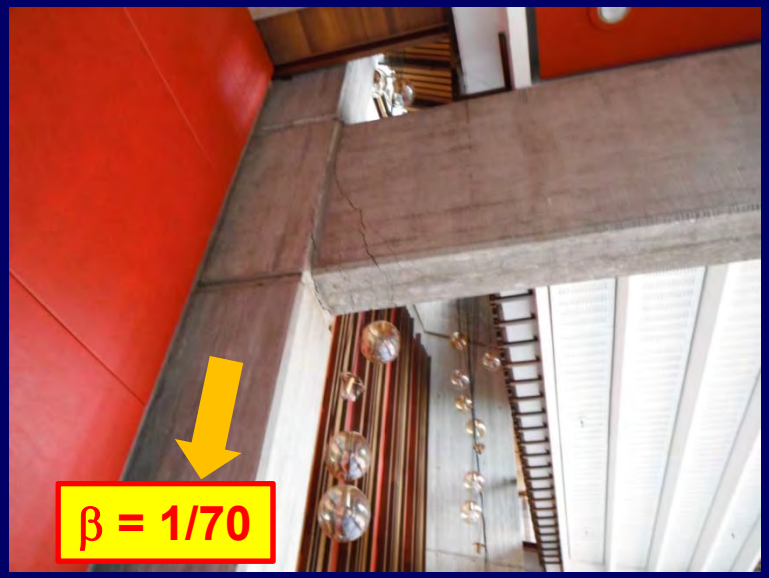
Cubrinovski et al.

Liquefaction Effects on Structures



Tilting and Sliding of Buildings

Settlement of Ground next to Piled Bldg.



Cracking due to Differential Settlement

Uniform Settlement of Building

CTUC Building

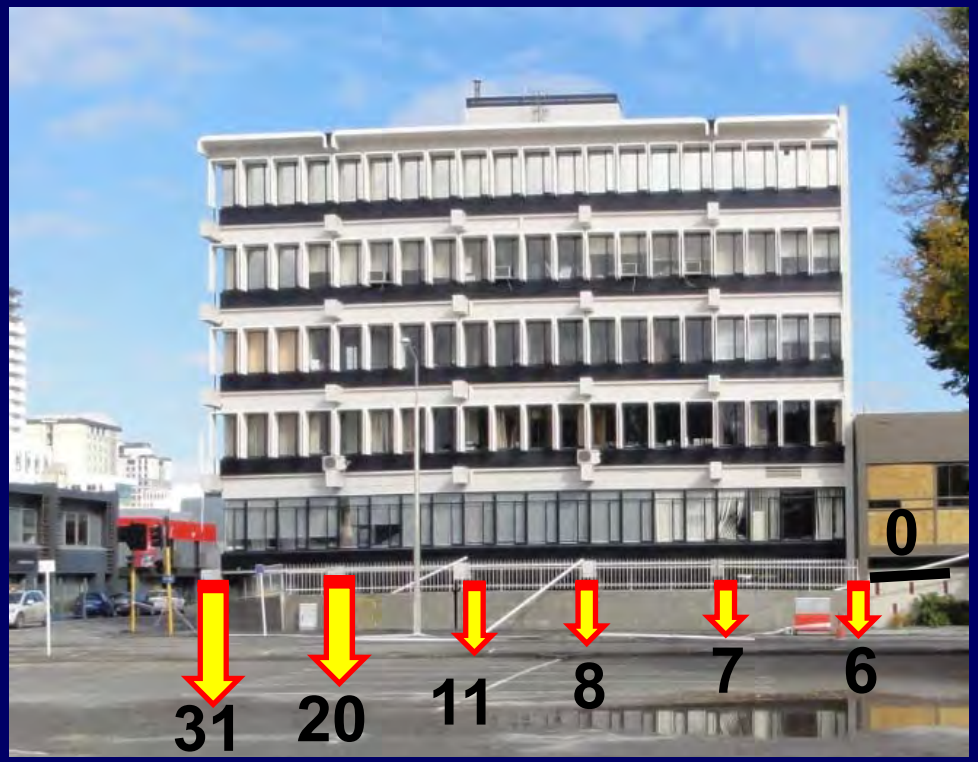
Liquefaction-Induced Differential Settlement Induces Distress

Building Settlement

GEER: Bray, Cubrinovski et al.

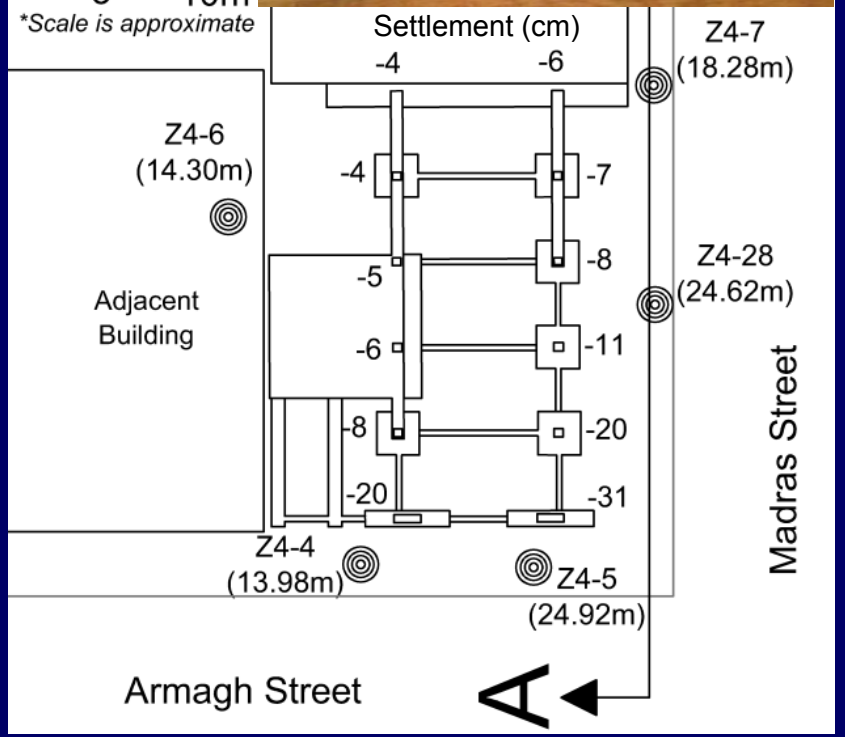
CTUC Building

Liquefaction-Induced Differential Settlement



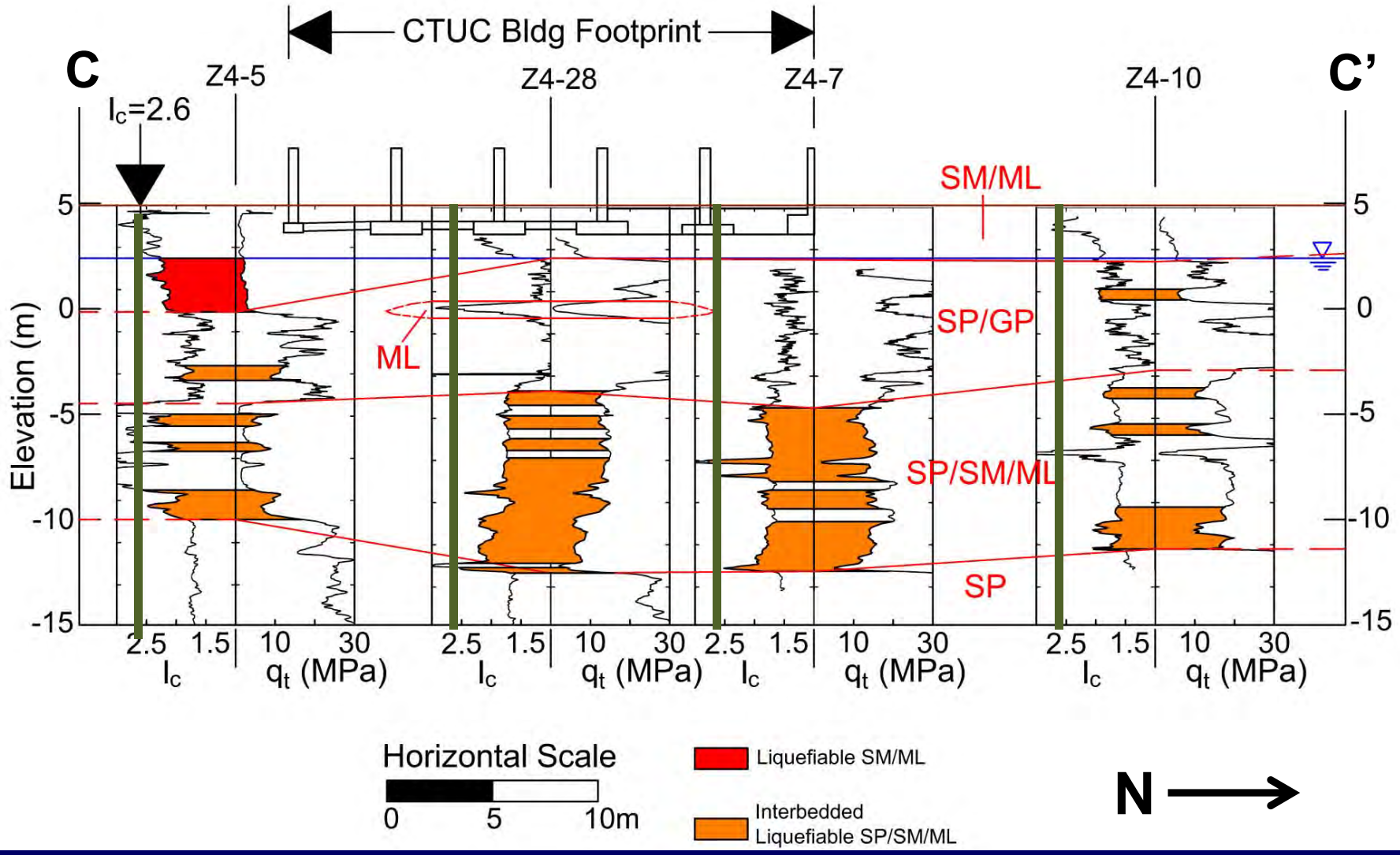
Building Settlement (cm)

Maximum Angular Distortion ≈ 1 / 50



GEER: Bray, Cubrinovski et al.

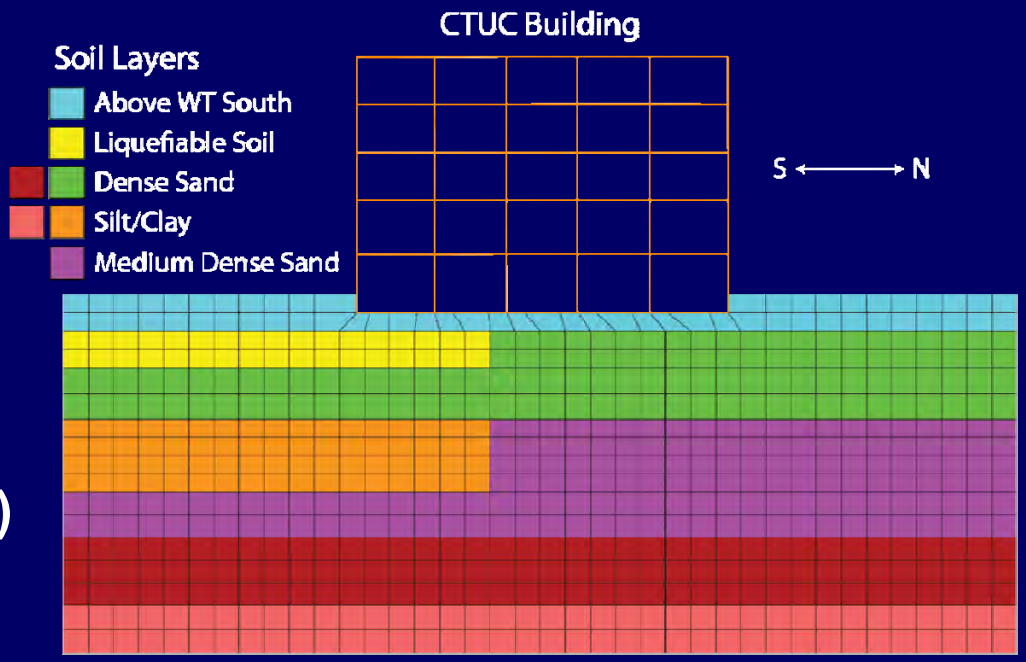
CTUC Building: Christchurch EQ

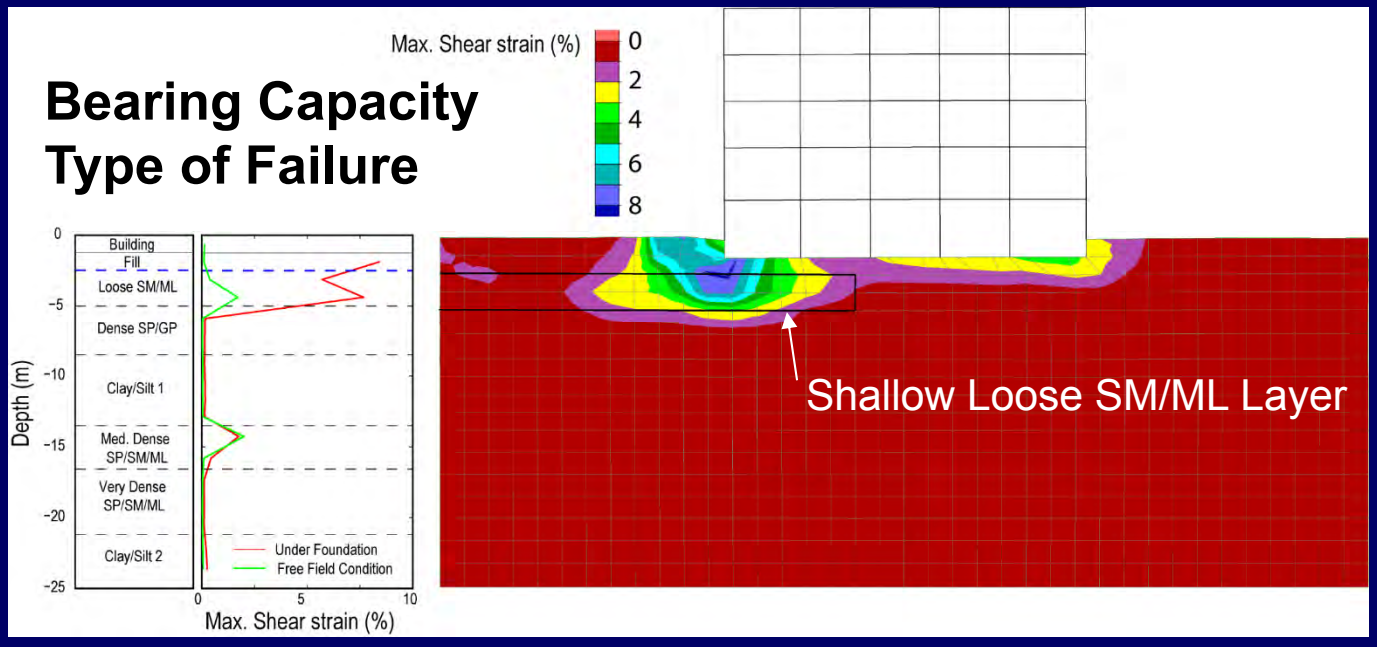


2011 Christchurch EQ: Robertson & Wride (1998)

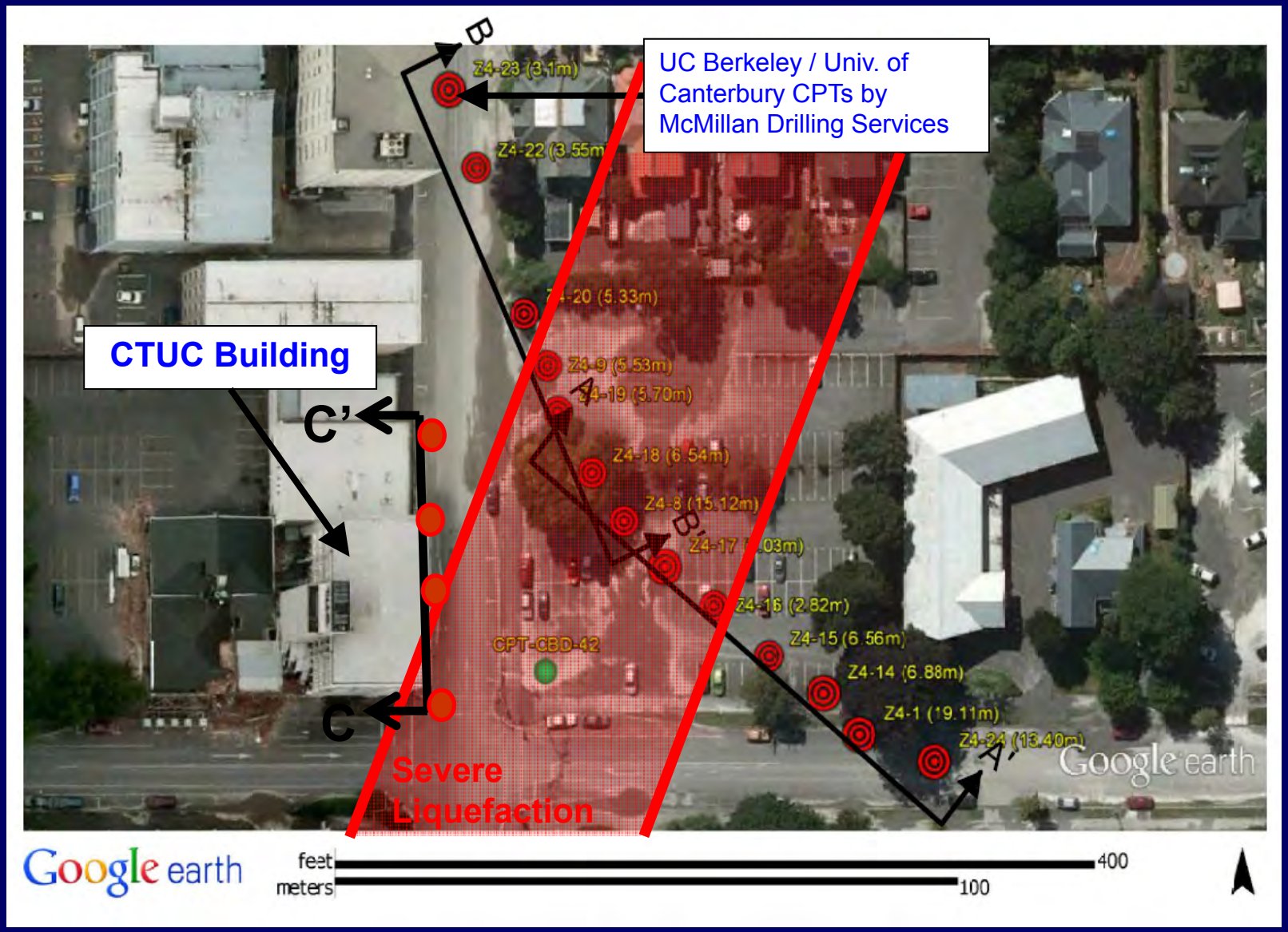
SSI Analyses of CTUC Building

FLAC Analyses with PM4Sand (Luque & Bray 2017)

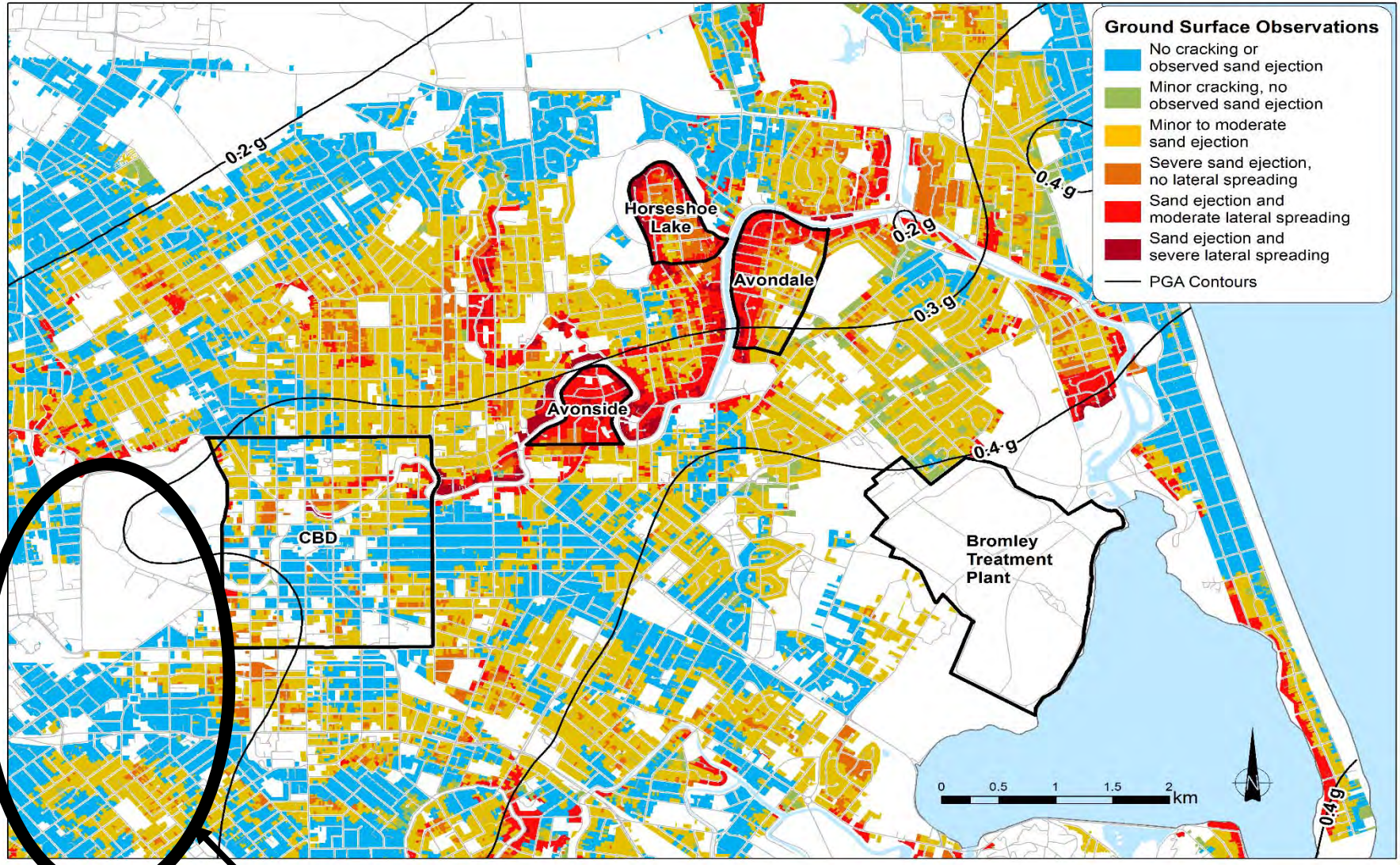




Liquefaction of Shallow Soil Deposits



Liquefaction in Christchurch



Relative lack of liquefaction

(van Ballegooy et al. 2014)

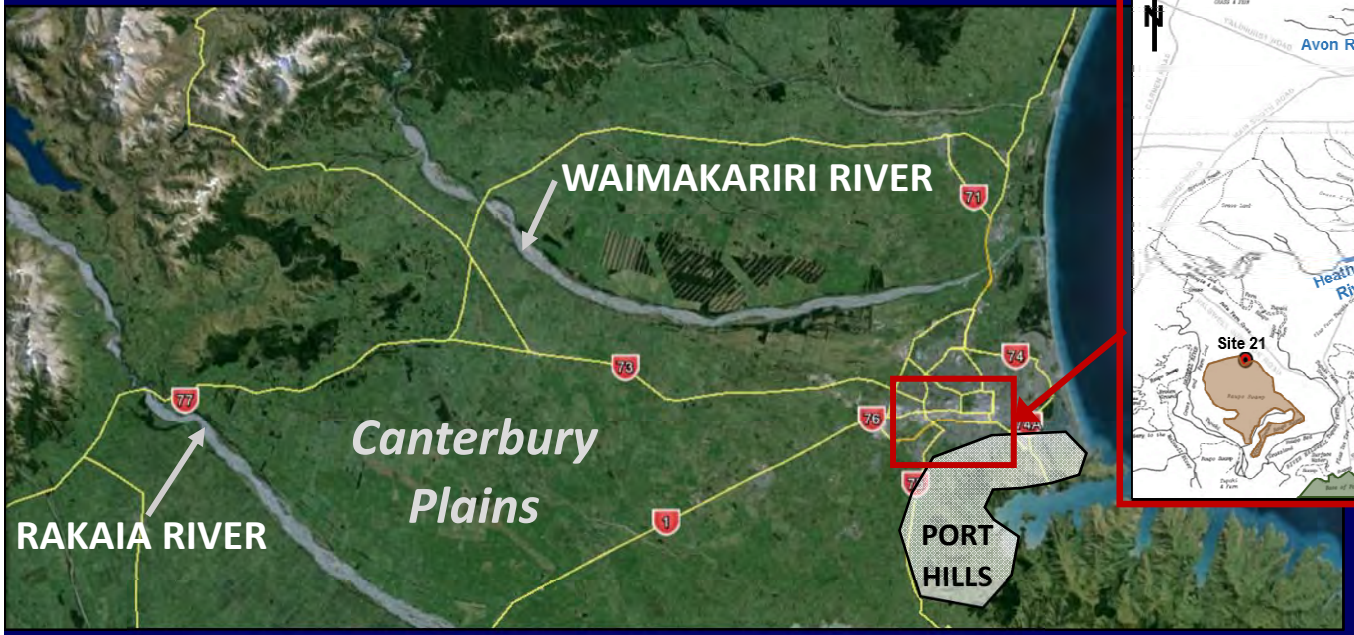
Non-Liquefaction of Silty Soil Sites

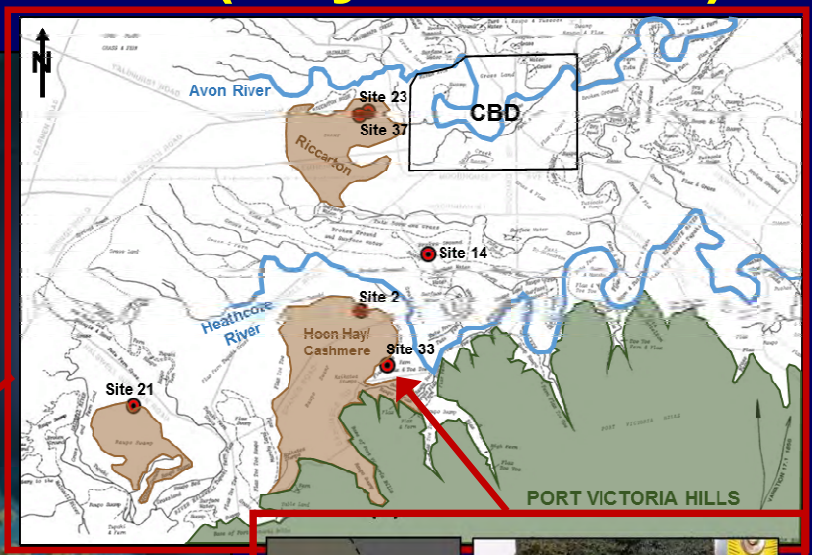
Site 23

site where no liquefaction effects were observed;
yet simplified procedures indicate liquefaction was expected

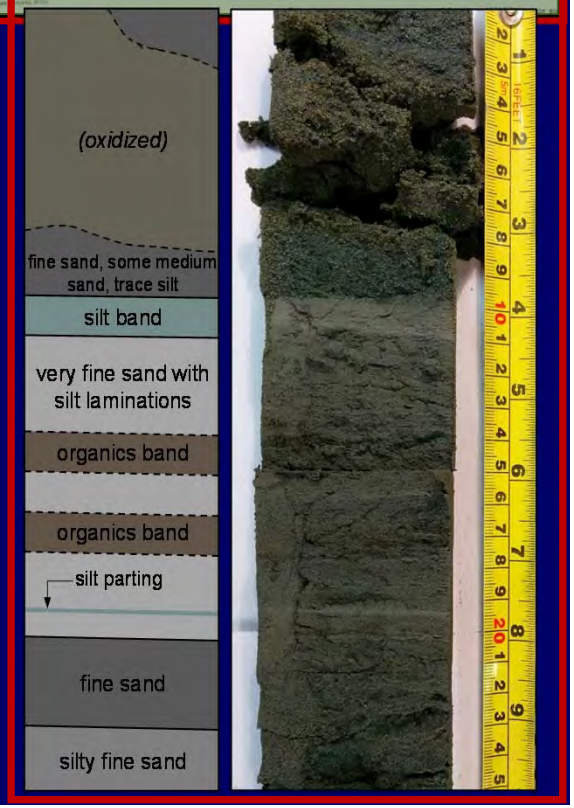
(from R. Wentz, Wentz-Pacific)

Depositional Environment (Beyzaei et al.)



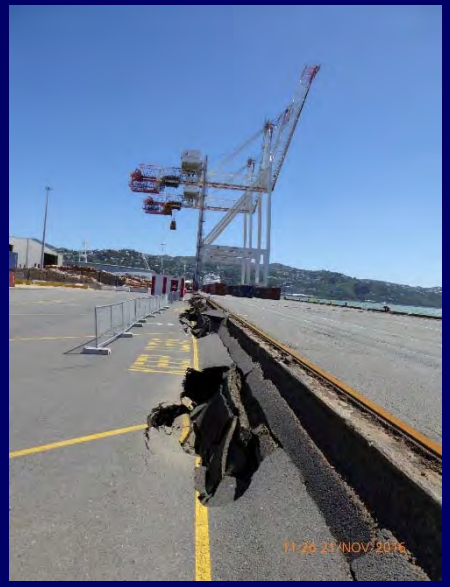


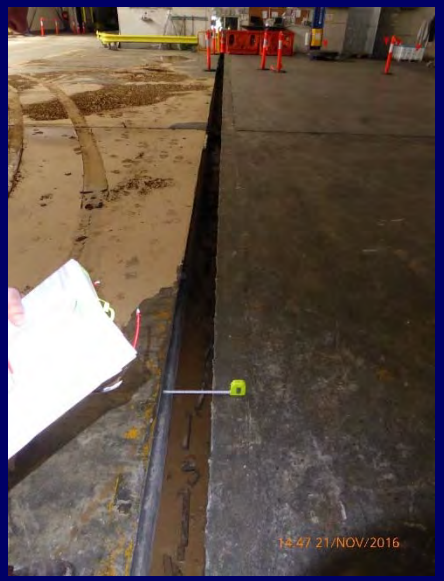
1918 Photo from Christchurch: Swamp to City



Liquefaction Effects on Ports

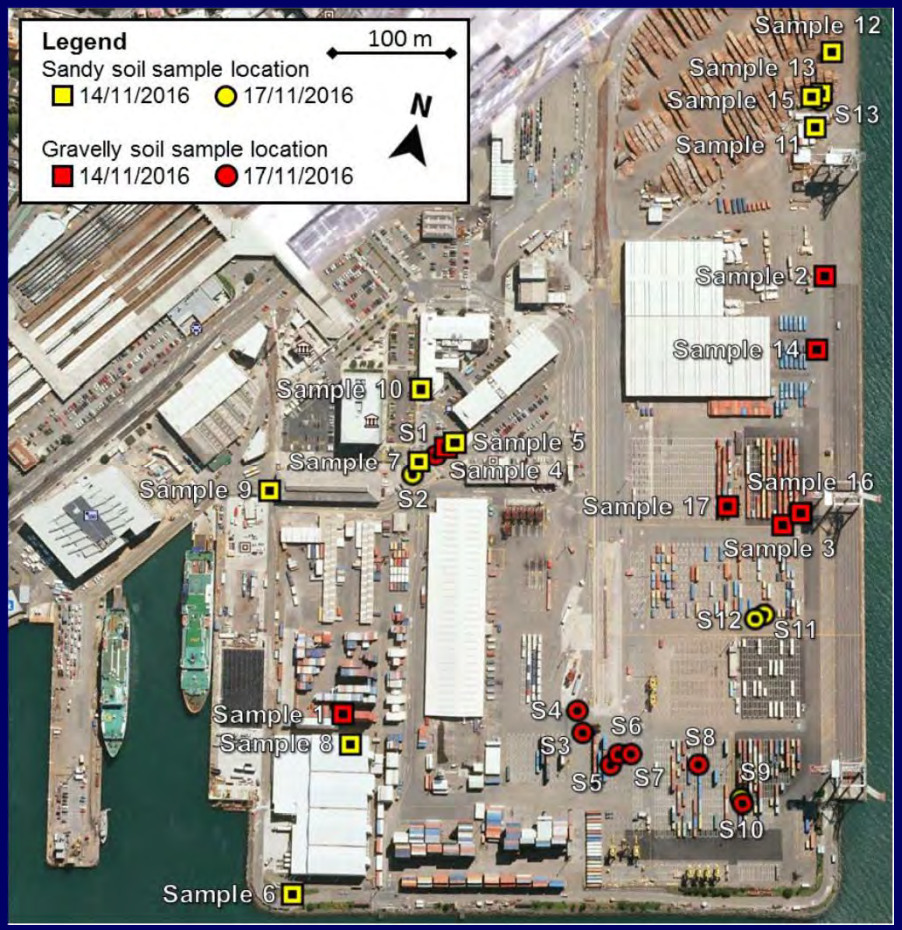
2016 Kaikoura EQ – CentrePort Wellington

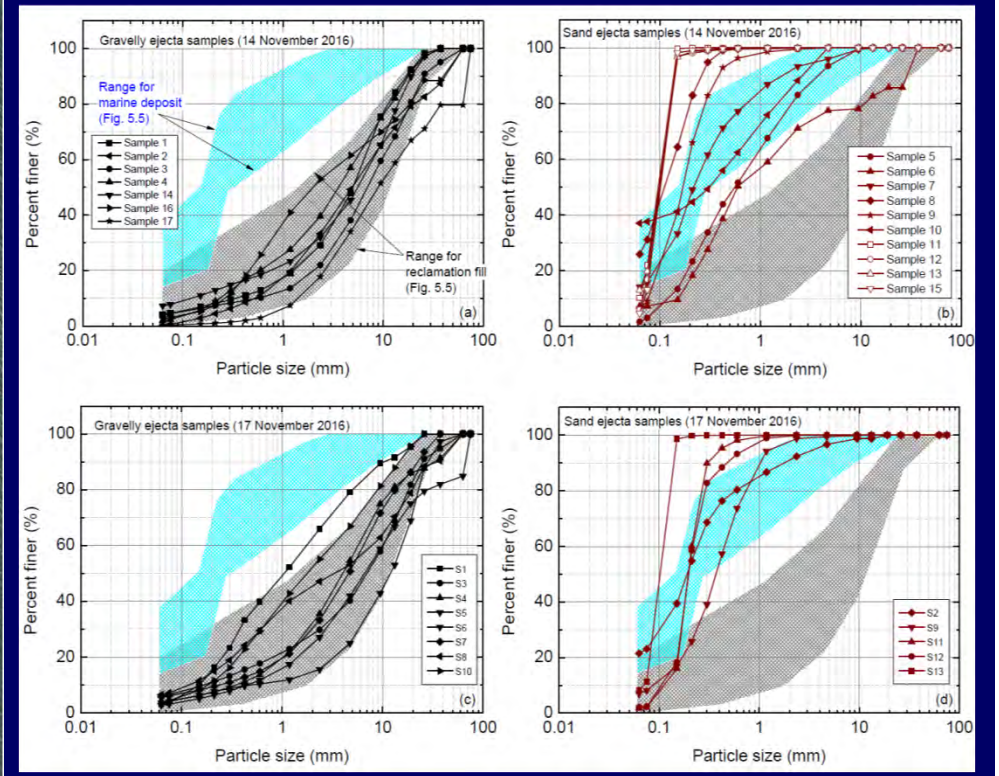




CentrePort Wellington – 2016 Kaikoura EQ

Documenting Sediment Ejecta

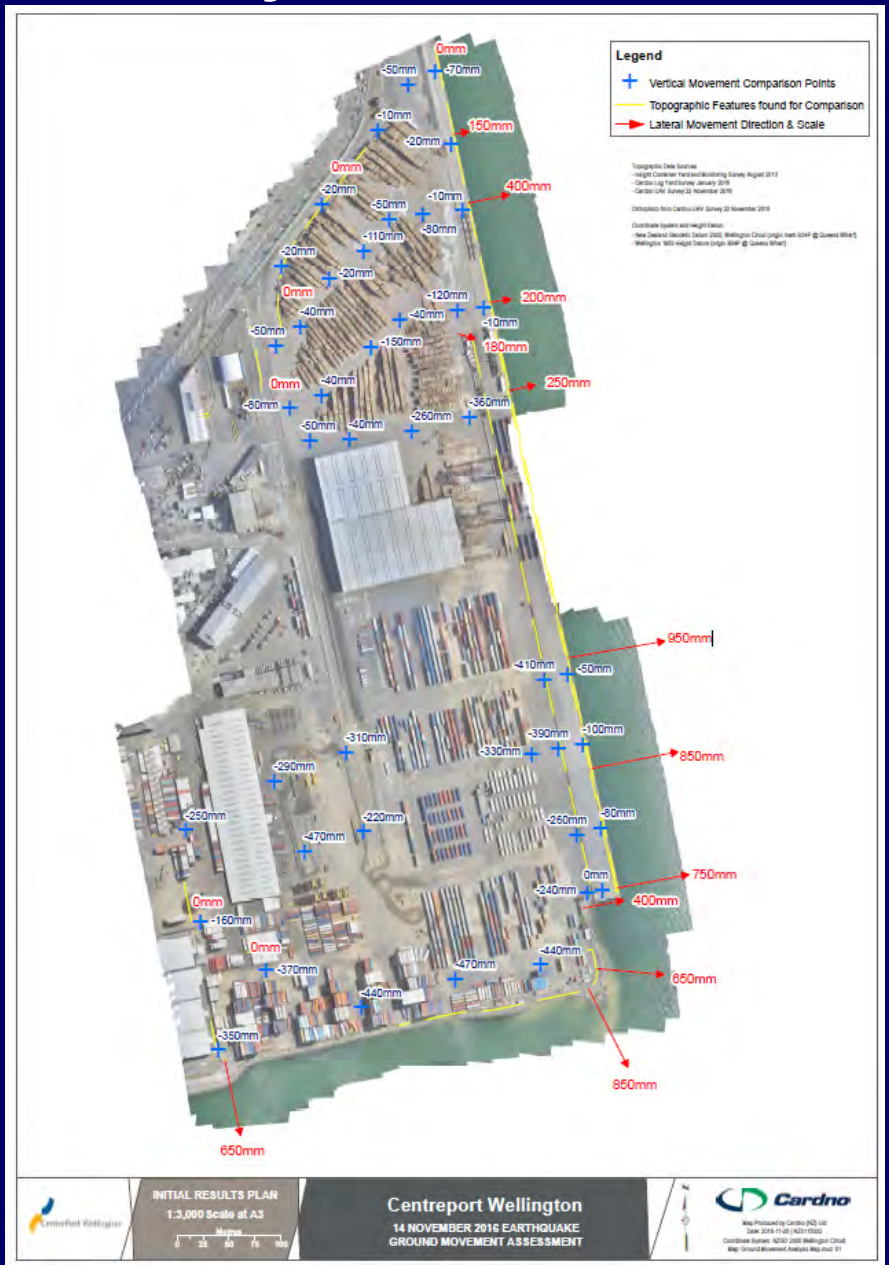




Cubrinovski et al. 2017 *NZBEE*

CentrePort Wellington – 2016 Kaikoura EQ

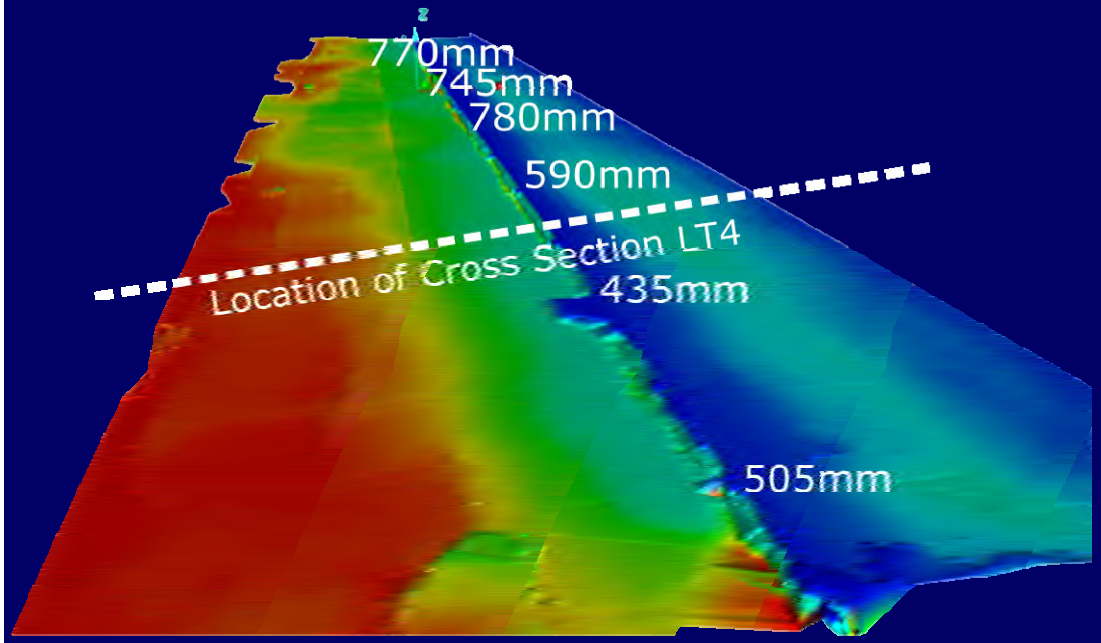
Aerial Survey - Structure from Motion (*Cardno*)

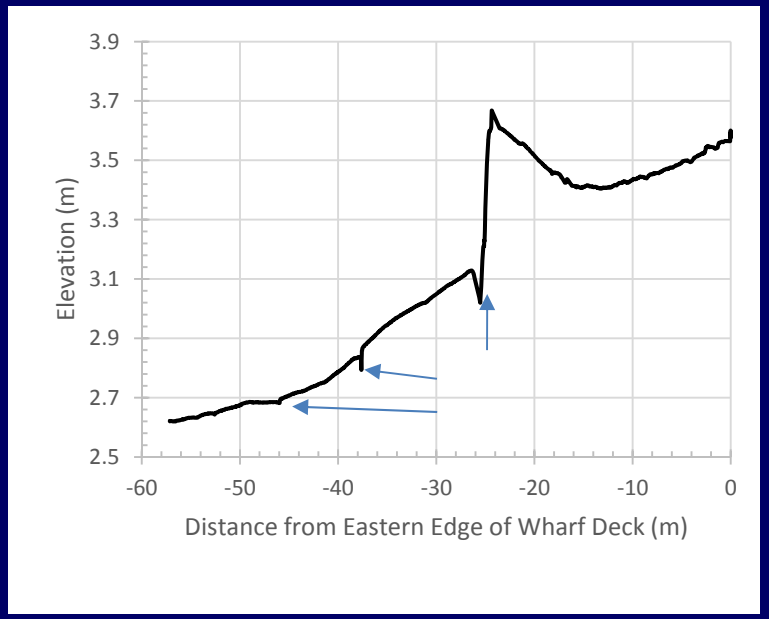


Cubrinovski et al. 2017 *NZBEE*

CentrePort Wellington – 2016 Kaikoura EQ

Ground Survey – LiDAR (*M. Olsen OSU*)

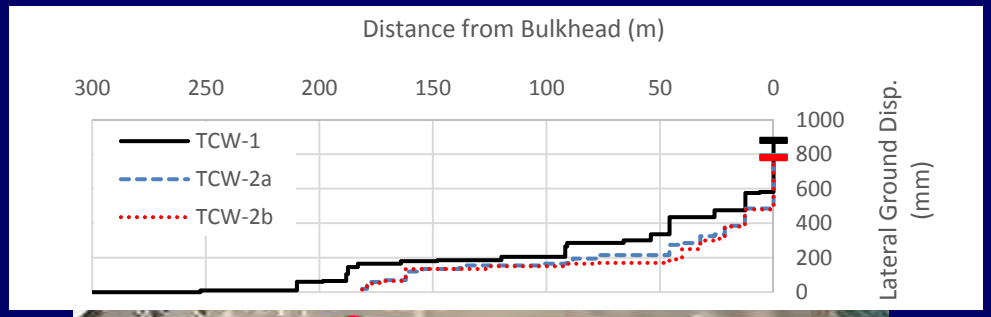


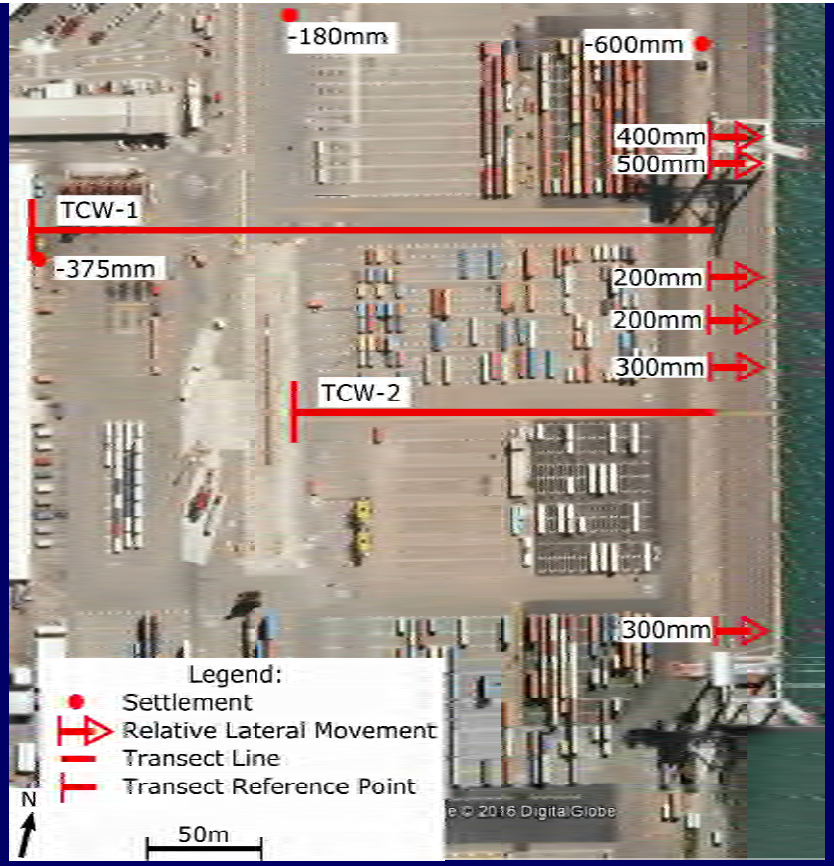


Cubrinovski et al. 2017 *NZBEE*

CentrePort Wellington – 2016 Kaikoura EQ

Ground Surveys of Liquefaction-Induced Lateral Movements

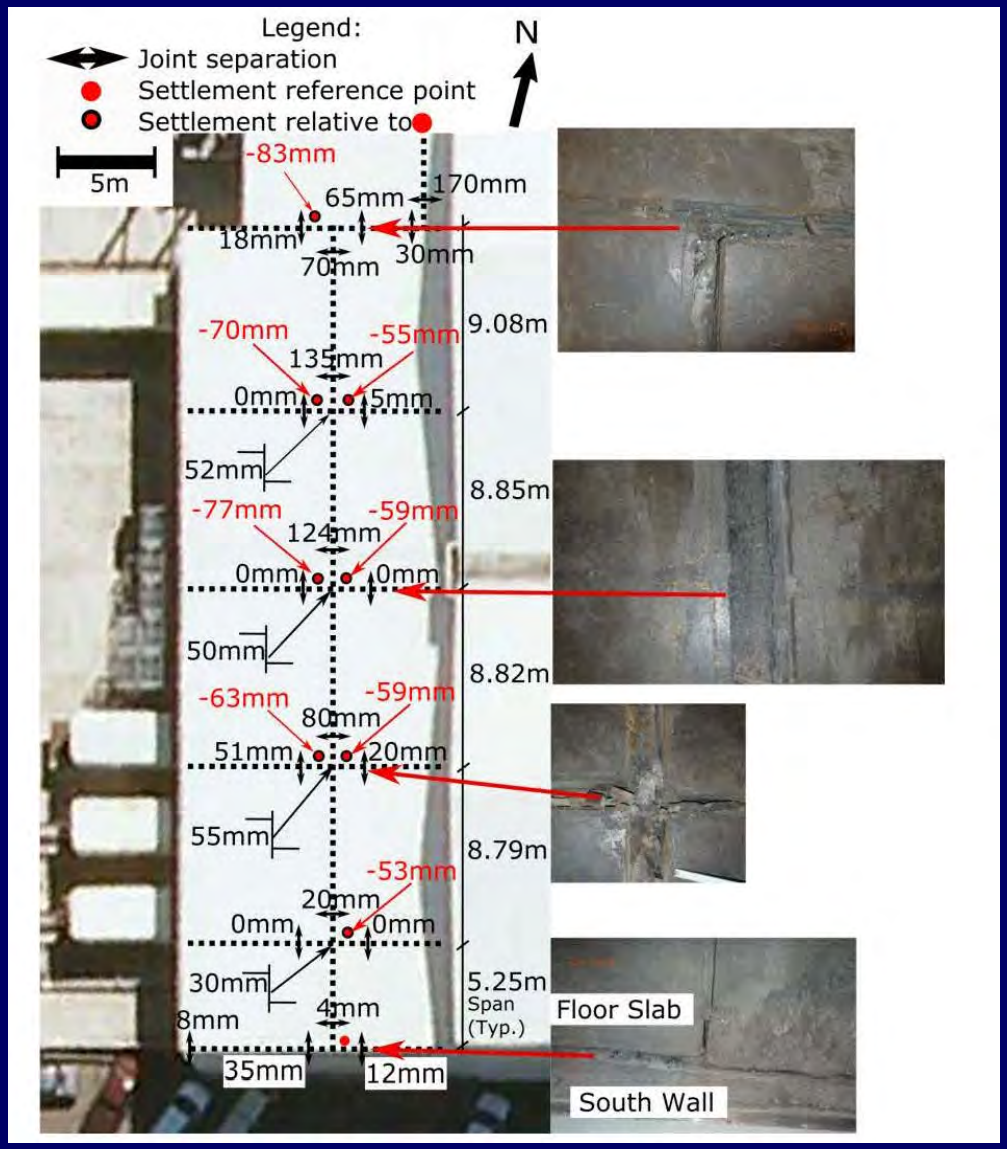




Cubrinovski et al. 2017 *NZBEE*

CentrePort Wellington – 2016 Kaikoura EQ

Documenting Liquefaction-Induced Building Damage



survey by Bray & de la Torre

Cubrinovski et al. 2017 *NZBEE*