Geotechnical Extreme Events Reconnaissance

Turning Disaster into Knowledge

Soil Liquefaction in the Christchurch Area during Recent Earthquakes

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with

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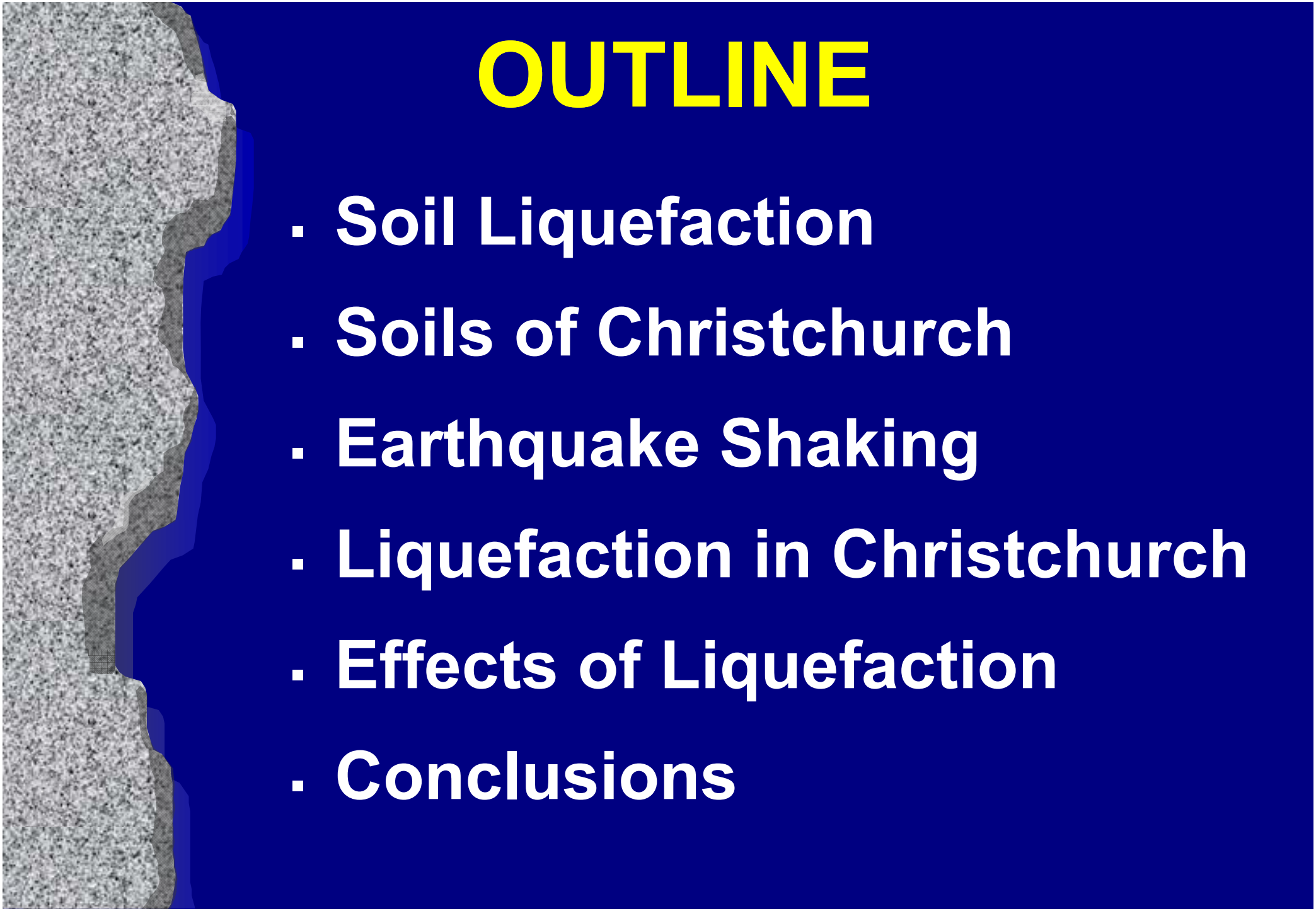
Sponsors: National Science Foundation & Earthquake Commission New Zealand


OUTLINE
Soil Liquefaction
Soils of Christchurch
Earthquake Shaking
Liquefaction in Christchurch
Effects of Liquefaction
Conclusions

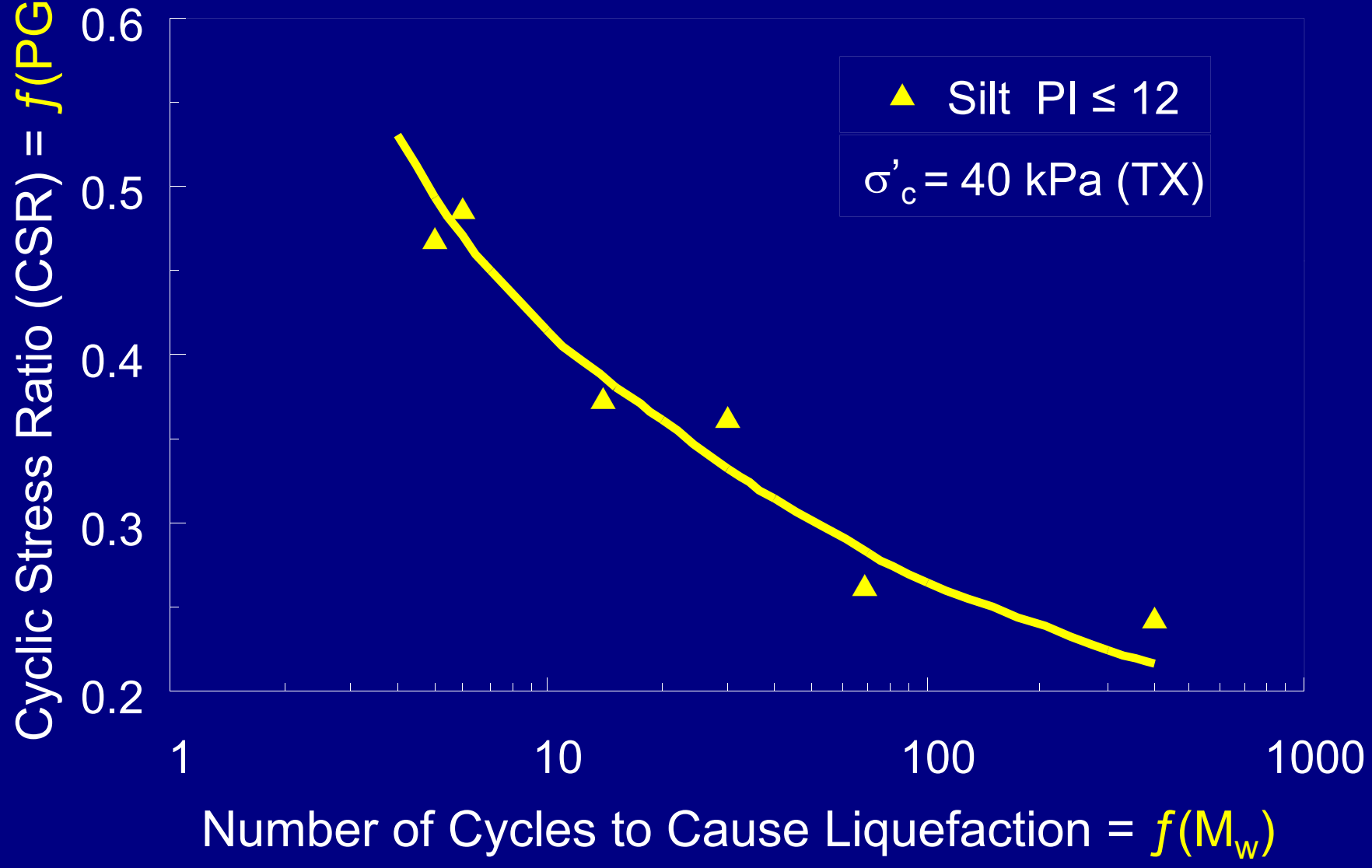
Soil Liquefaction

1964 Niigata, Japan EQ (from H.B. Seed)

1989 Loma Prieta EQ

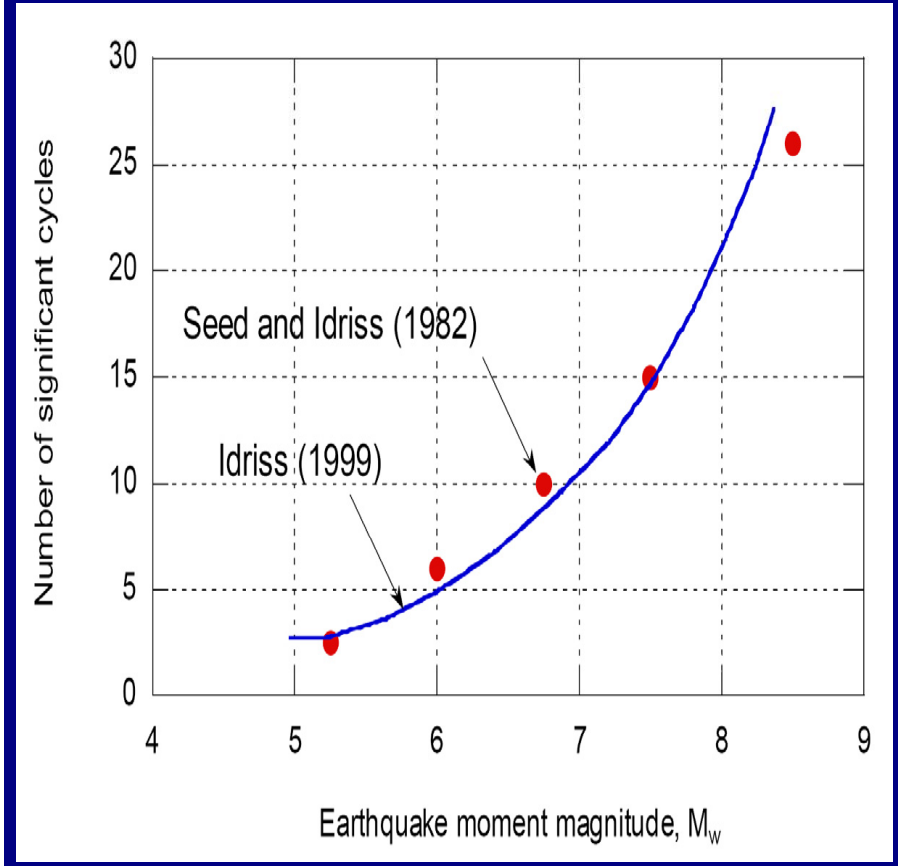
1906 San Francisco EQ (Lawson et al. 1908)

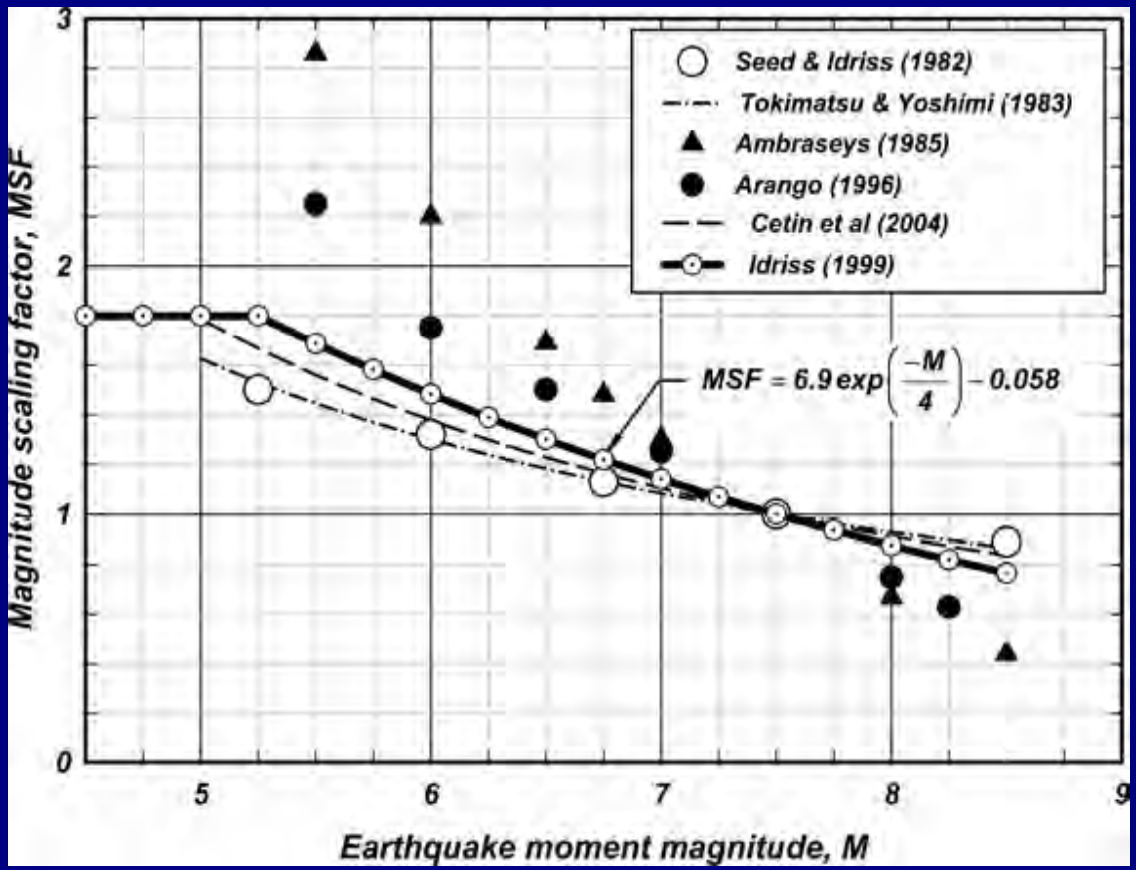
Liquefaction Testing on Adapazari Silt
(Bray & Sancio 2006)



Magnitude Scaling Factor

$$CSR_{M7.5} = CSR_M / MSF$$

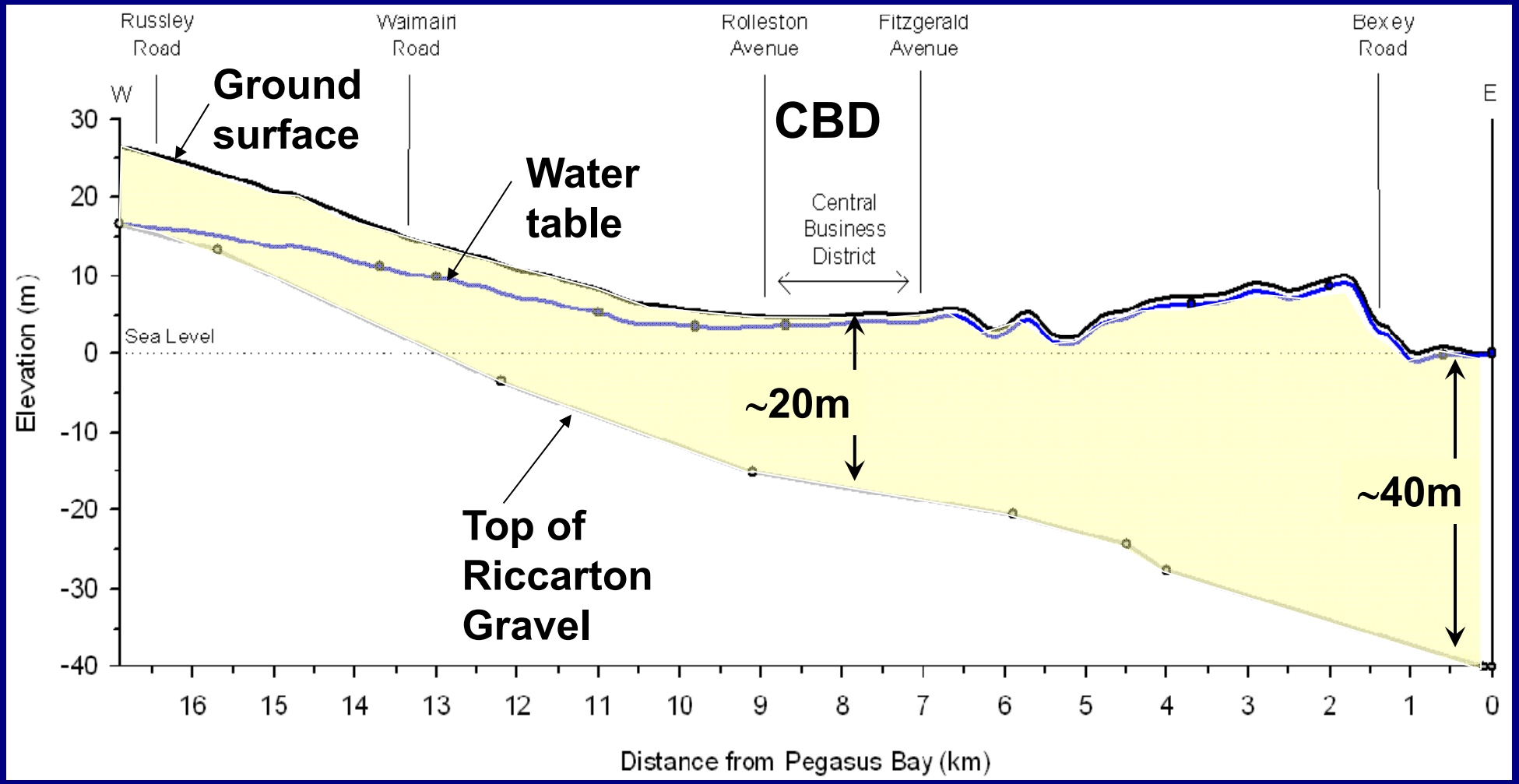




(from Idriss & Boulanger 2008)

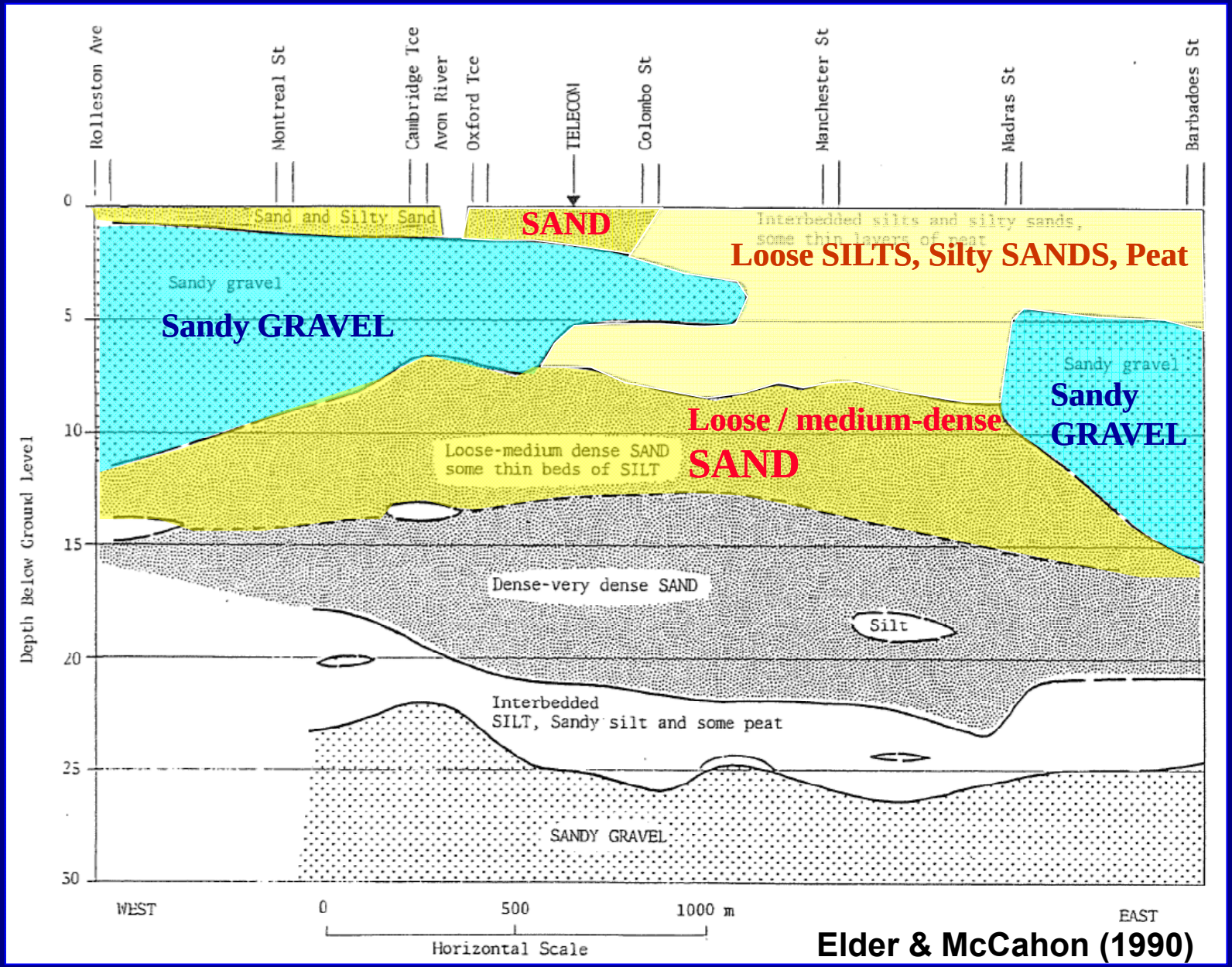
Canterbury Plains

East-West Cross Section through Christchurch



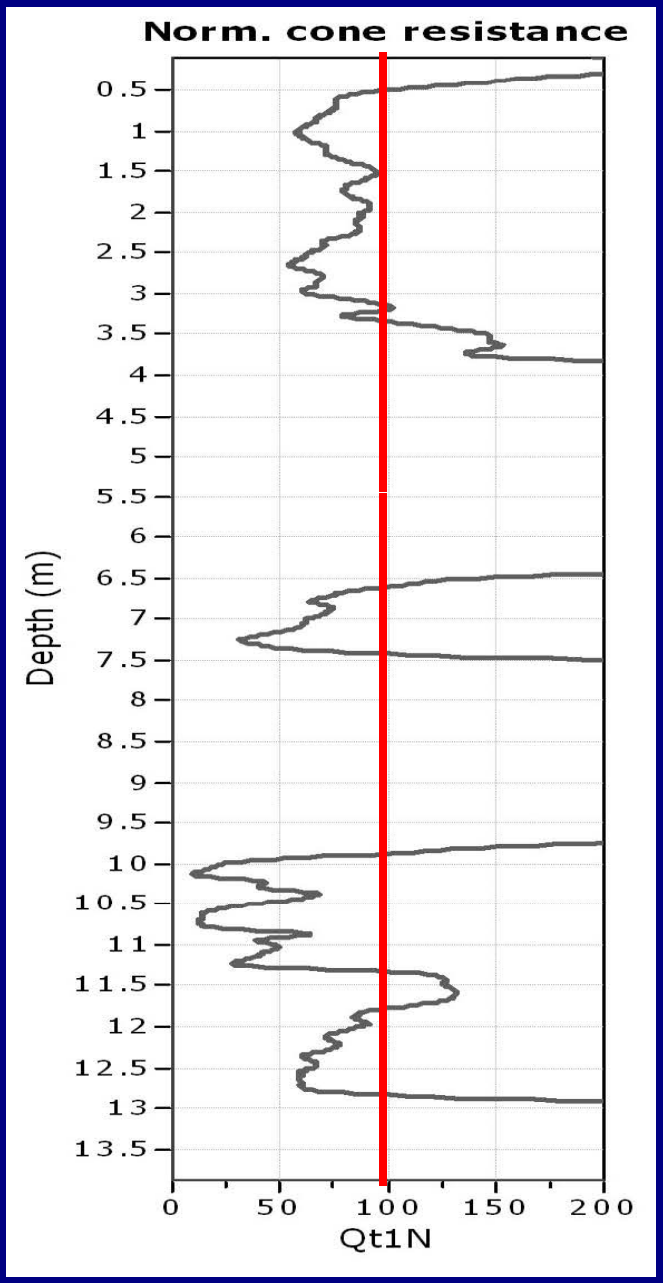
from M. Cubrinovski

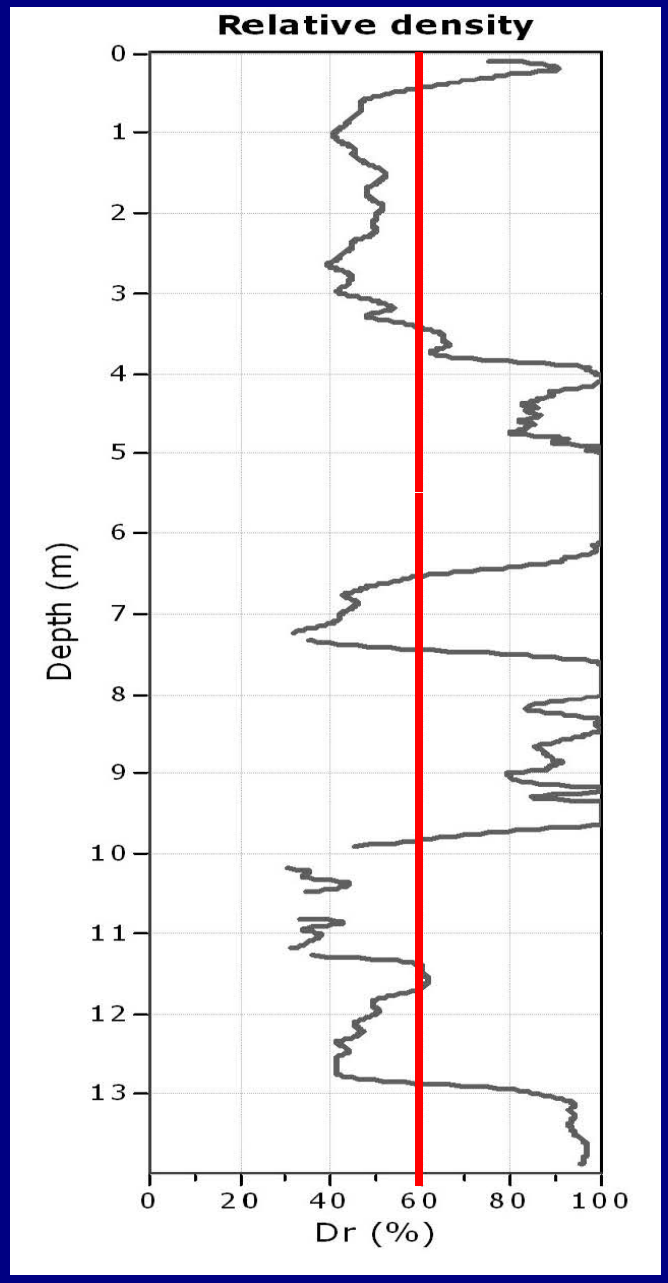
Hereford Street Soil Profile

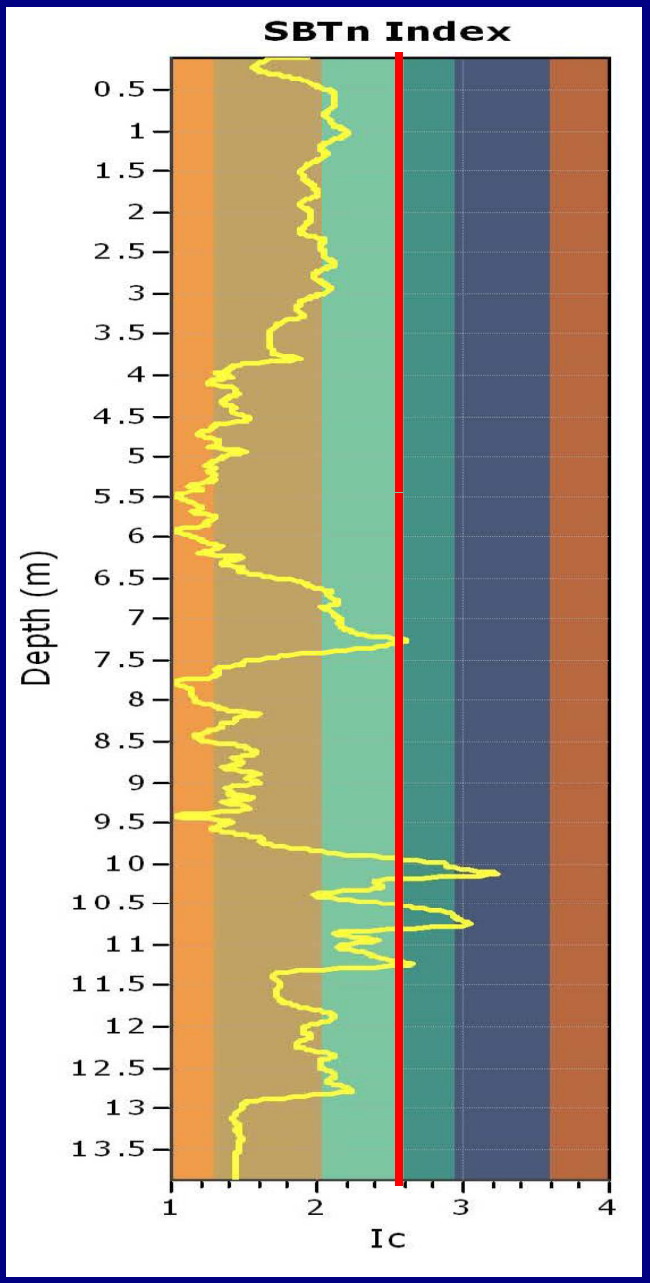


Elder & McCahon (1990)

Subsurface Profile at Madras & Armagh Sts.

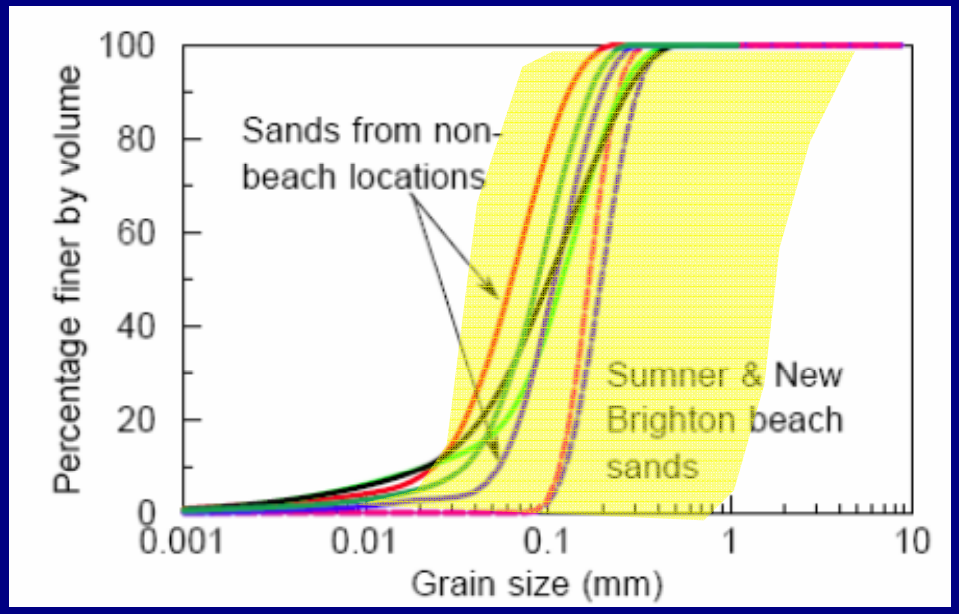






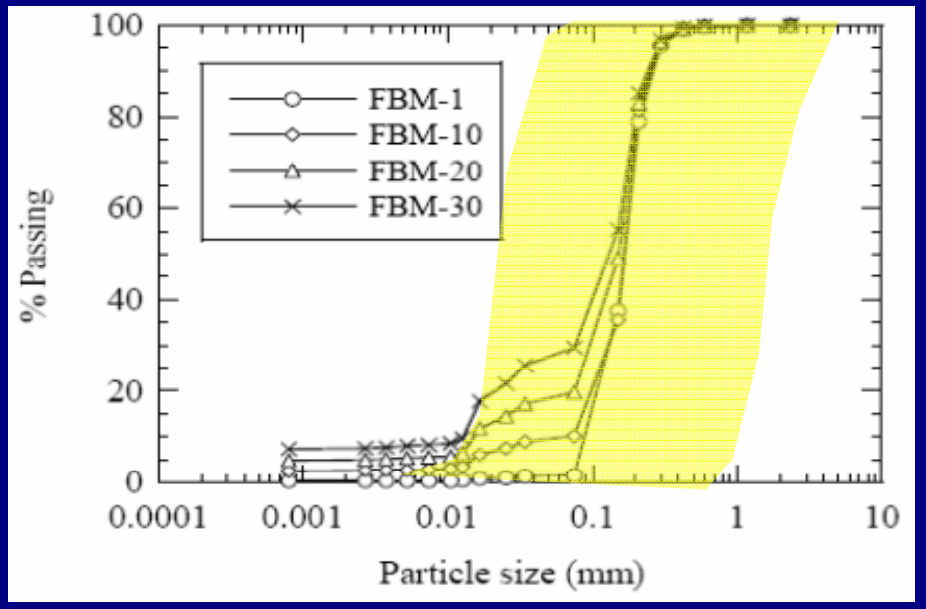
Grain-Size Composition of Soils

Sand ejecta samples



(courtesy of M. Pender, UA)

Fitzgerald Bridge samples



Cubrinovski et al. (2008, 2010); Rees (2010)

- **Clean sands and non-plastic silty sands**
- **Soils are susceptible to liquefaction**

from M. Cubrinovski

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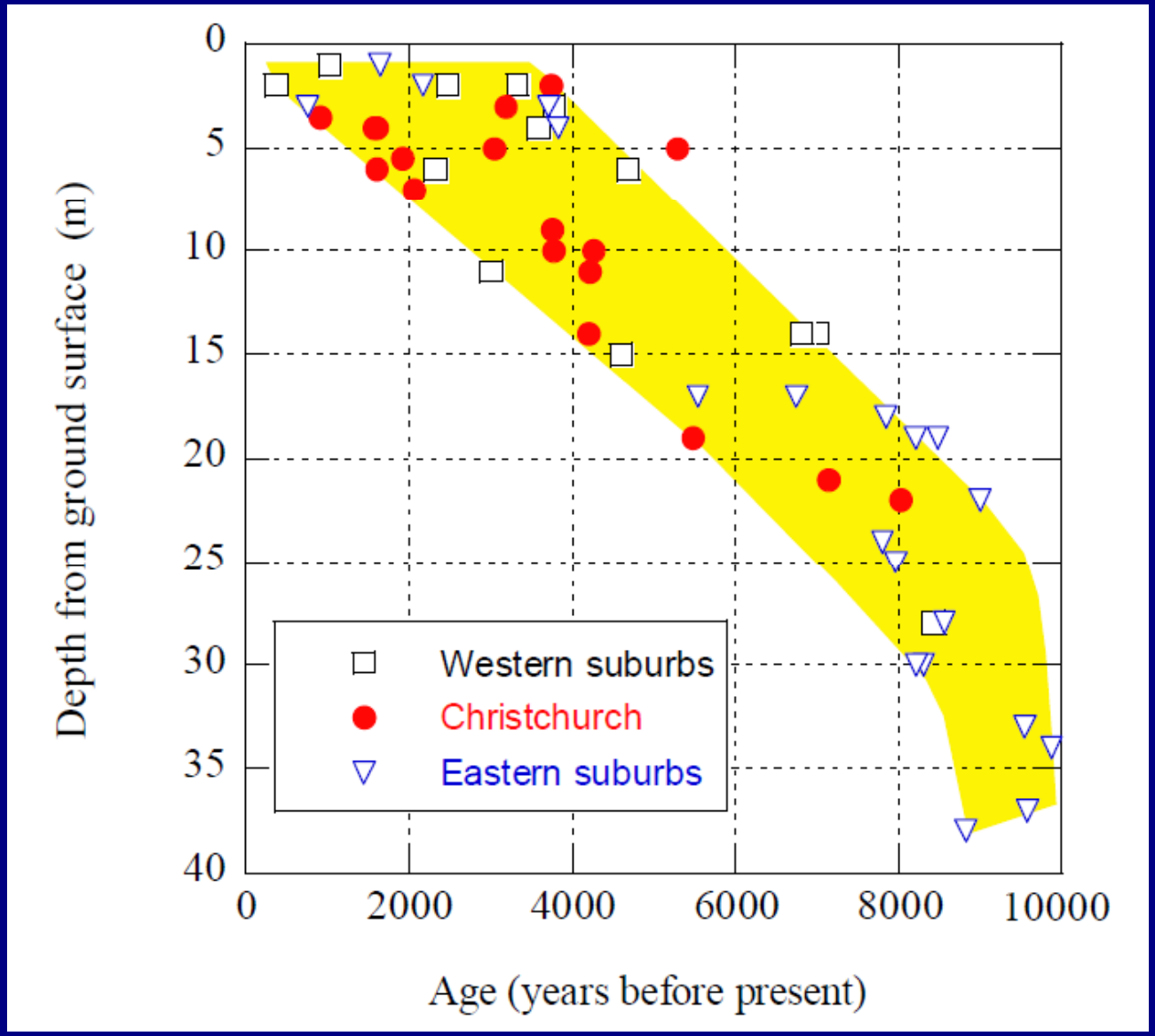
Age of Christchurch Soils



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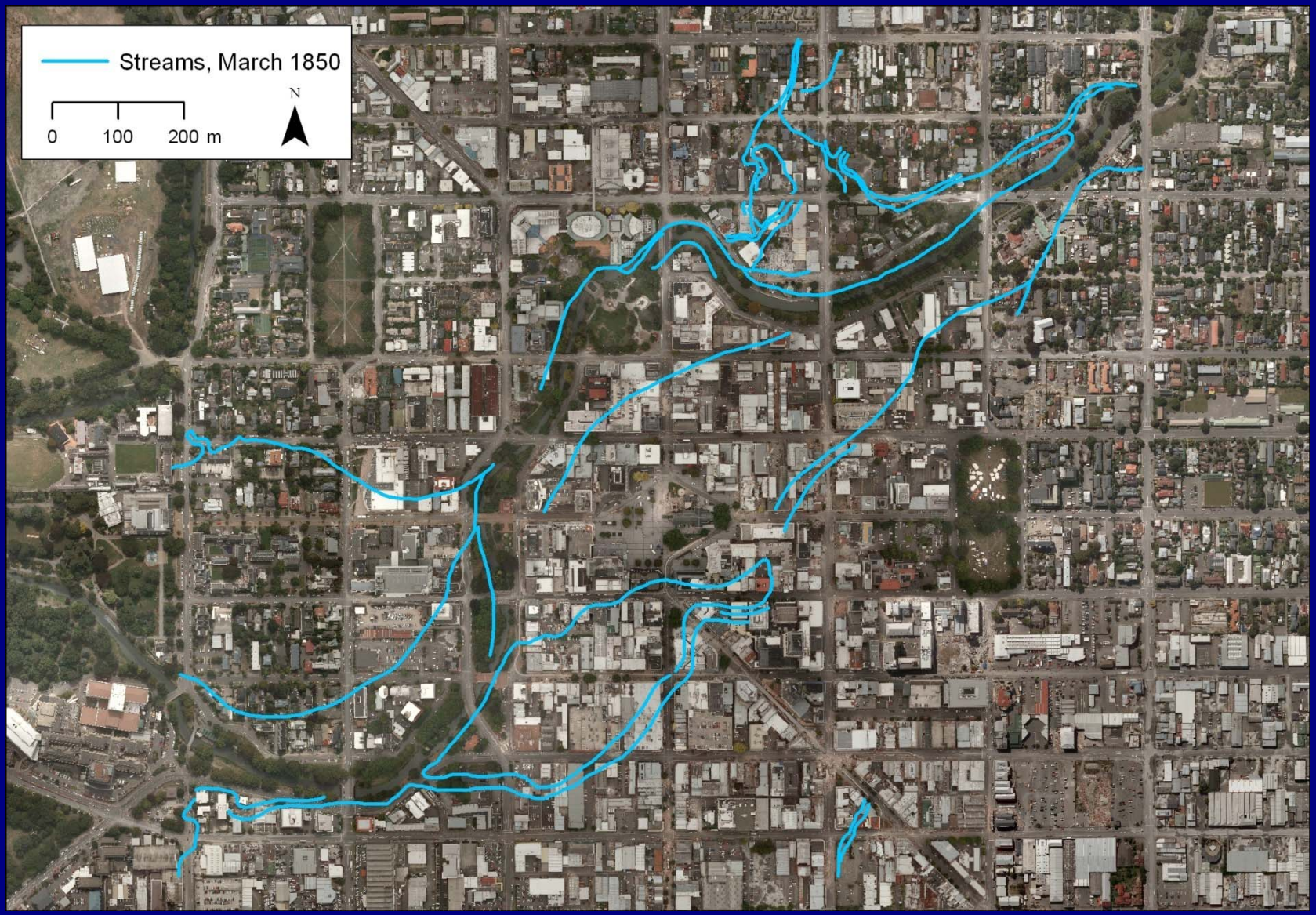
Streams in Central Christchurch (from1850's 'Black Maps')



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CHRISTCHURCH NEW ZEALAND

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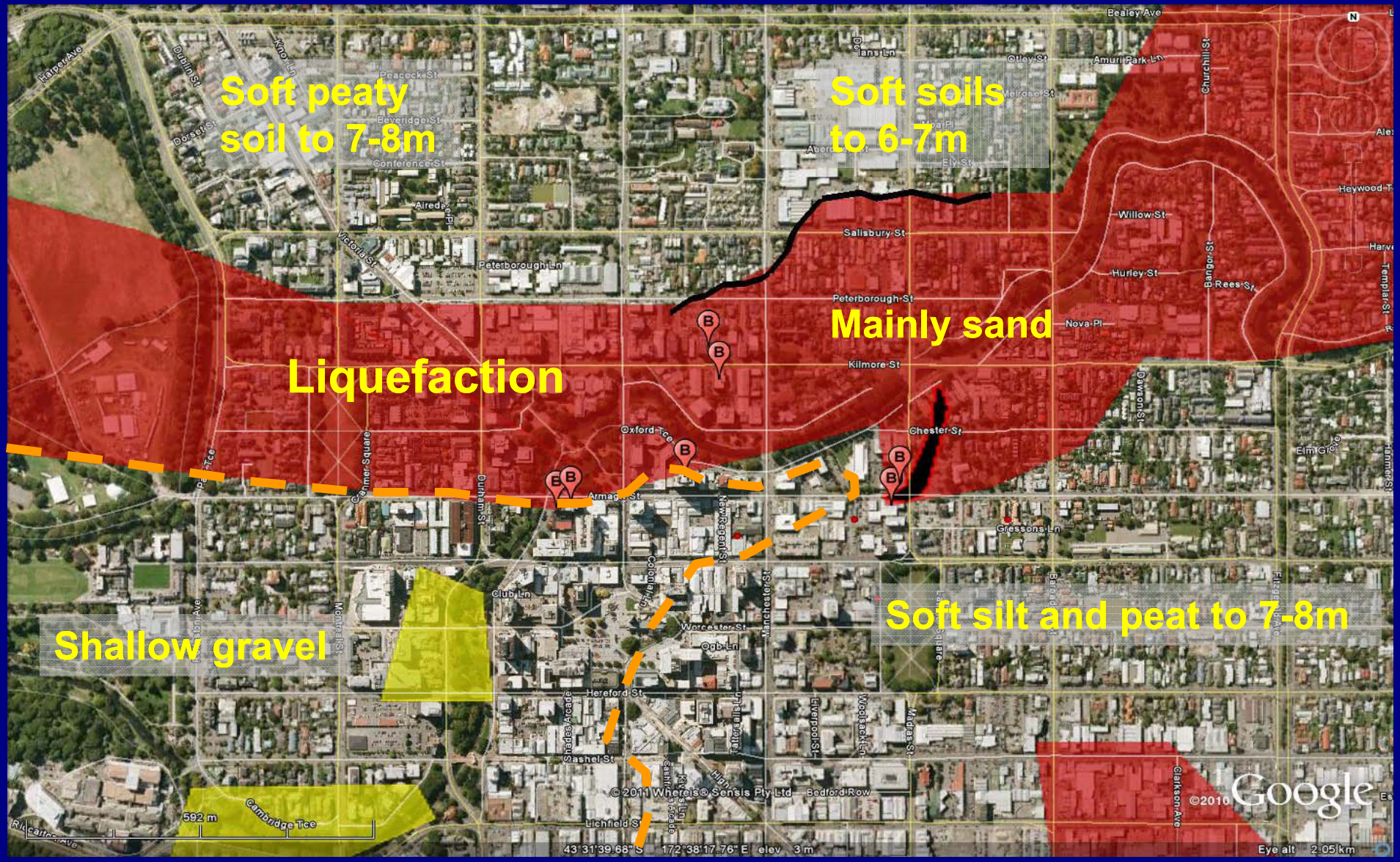
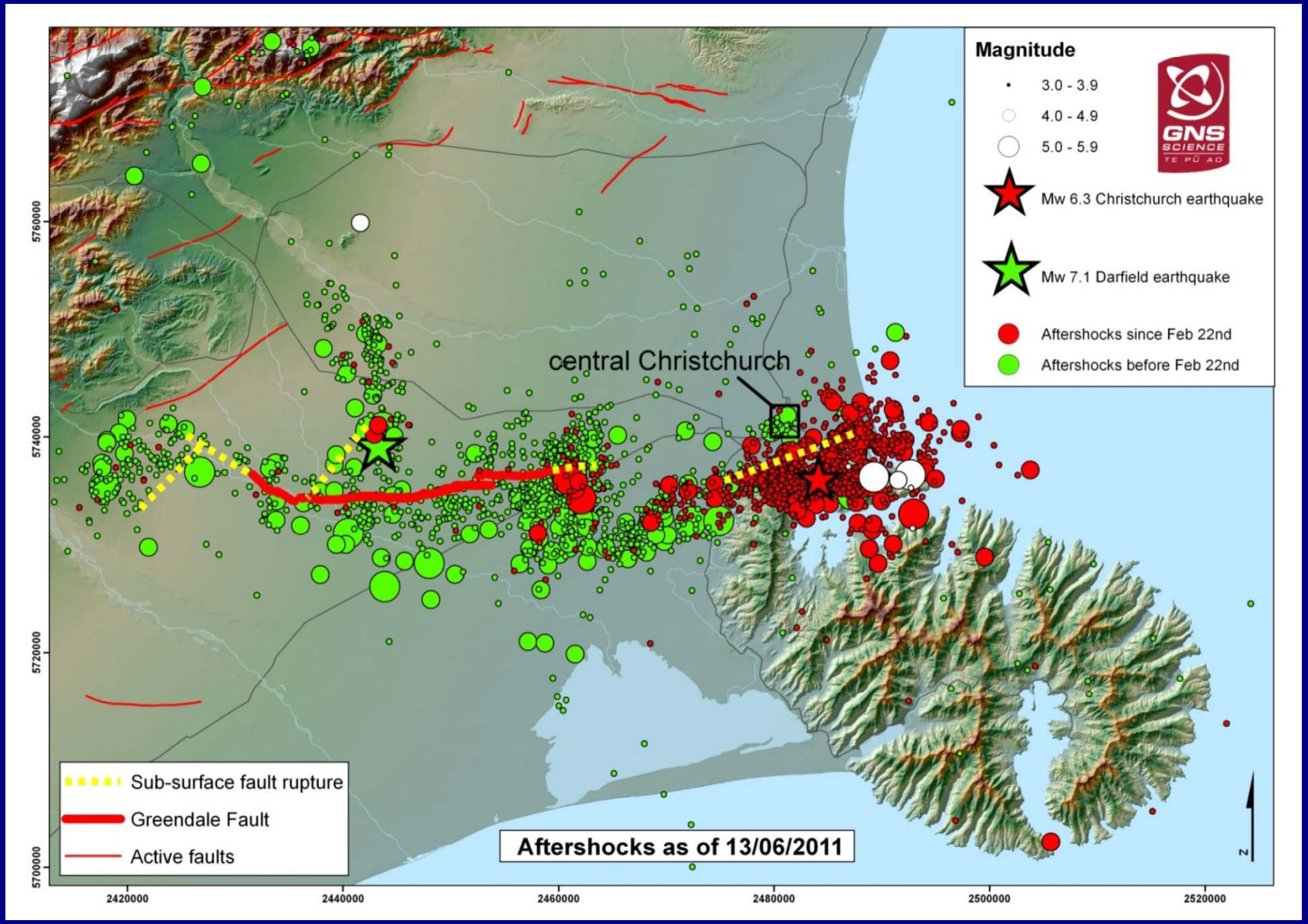
Central Business District: Liquefaction 22 Feb 2011



Cubrinoski et al. (2001)

2010-2011 Christchurch Earthquakes



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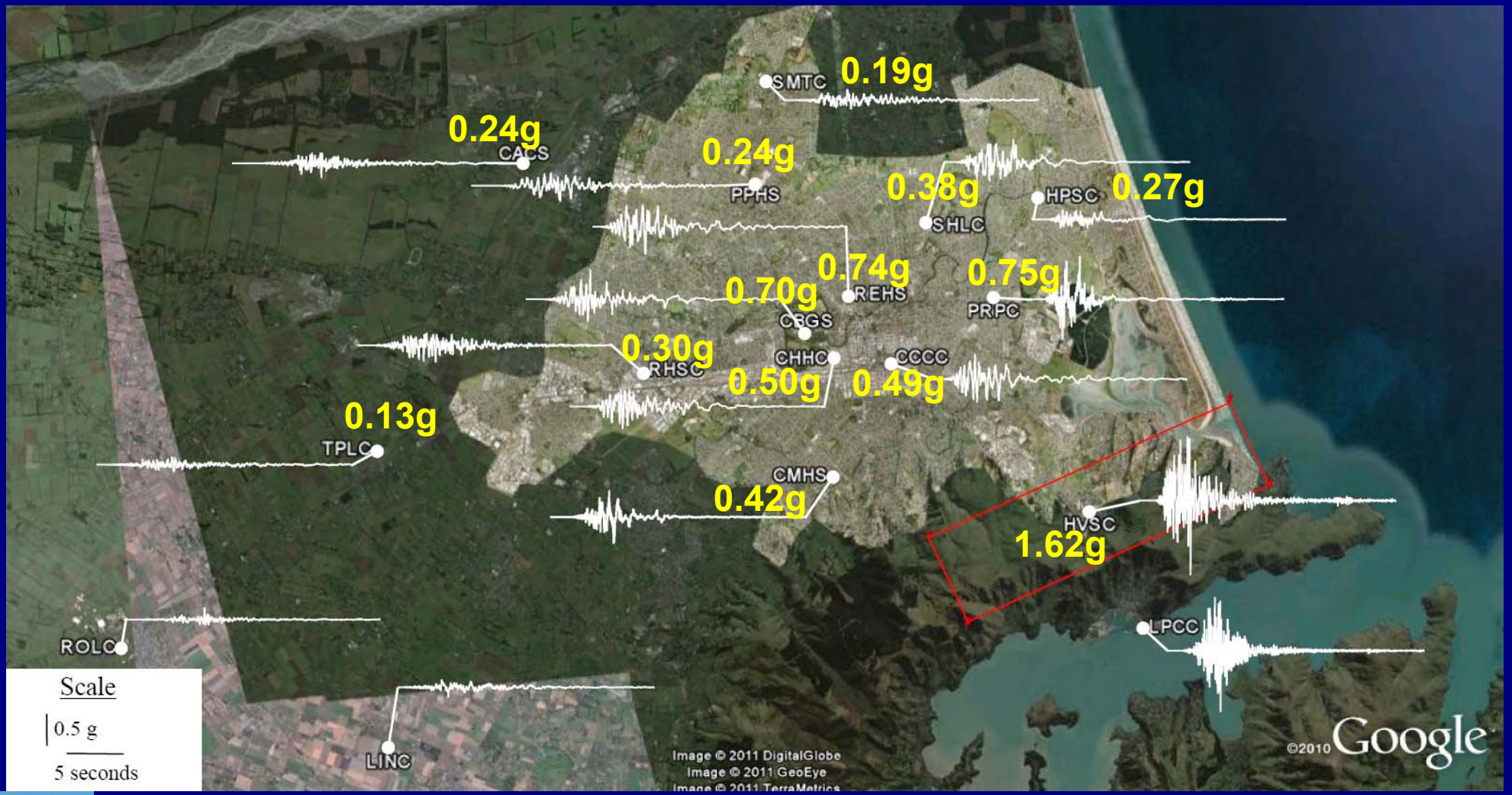
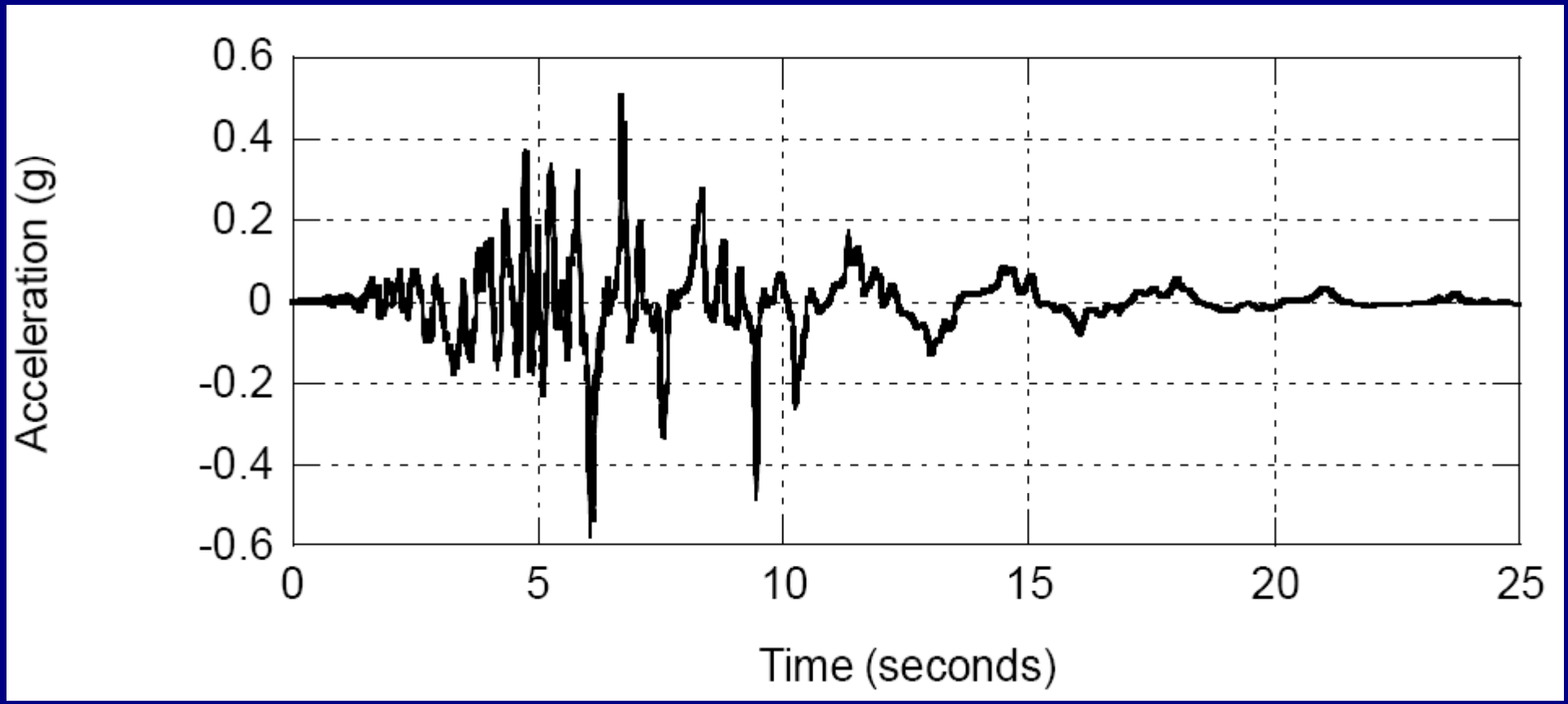
Fault-Normal Horizontal Acceleration Time Histories

22 Feb 2011 Christchurch Earthquake (PGA)



from Bradley (University of Canterbury)

Liquefaction Effects on Recorded Ground Motions



Recorded at the Botanic Garden (CBGS) site during the 22 Feb 2011 EQ

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from Bradley (University of Canterbury)

Seismic Demand from Recent EQs

Event	Median PGA (g)				Magnitude Scaling Factor (Youd et al. 2001)	Median $CSR_{M7.5}$	Level of Liquefaction in CBD
	CBGS	CCCC	CHHC	REHS			
4 SEP 10 $M_w = 7.1$	0.16	0.22	0.17	0.25	1.15	0.11	Low
26 DEC 10 $M_w = 4.8$	0.27	0.23	0.16	0.24	2.00	0.07	None
22 FEB 11 $M_w = 6.2$	**0.50**	**0.43**	**0.37**	**0.52**	**1.63**	**0.18**	**Severe**
13 JUN 11 $M_w = 5.3$	0.18	-	0.20	0.19	2.00	0.06	None
13 JUN 11 $M_w = 6.0$	0.16	-	0.22	0.26	1.77	0.08	Low

$CSR_{M7.5} = 0.65\ (PGA/g) / MSF$

$MSF = 10^{2.24}/M_w^{2.56} \leq 2.00$

Liquefaction at Porritt Park

4 Sep 2010 EQ - $CSR_{M7.5}$ = 0.11

22 Feb 2011 EQ - $CSR_{M7.5}$ = 0.18

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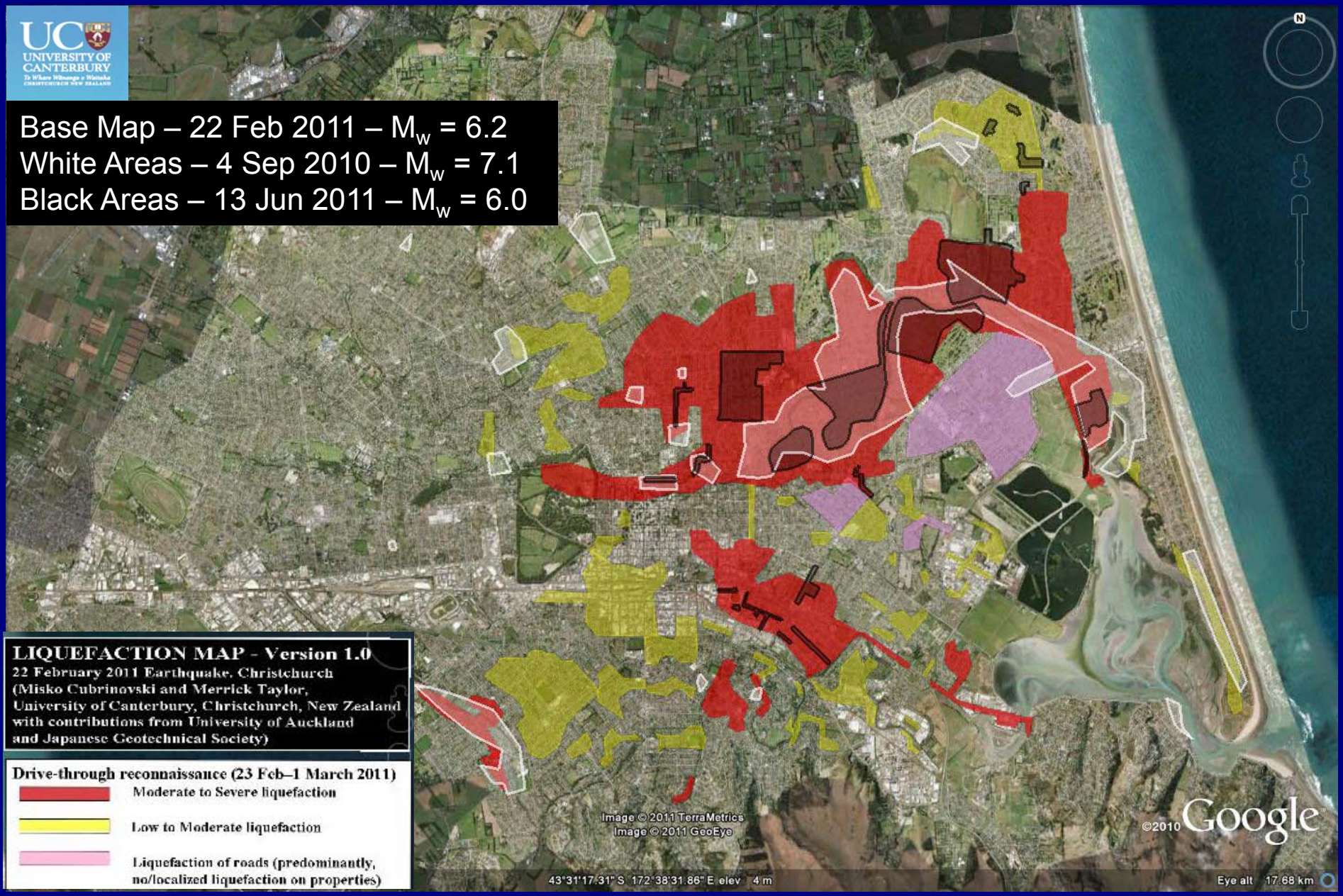
Liquefaction from 3 EQs (Cubrinovski 2011)



Severe Liquefaction in Suburbs

- **Large areas covered by thick sand ejecta**
- **Large subsidence in some suburbs**

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Damage to Residential Buildings

- ~ 1.5 m wide cracks
- Severe damage to foundations & houses

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Repeated Liquefaction in Some Suburbs

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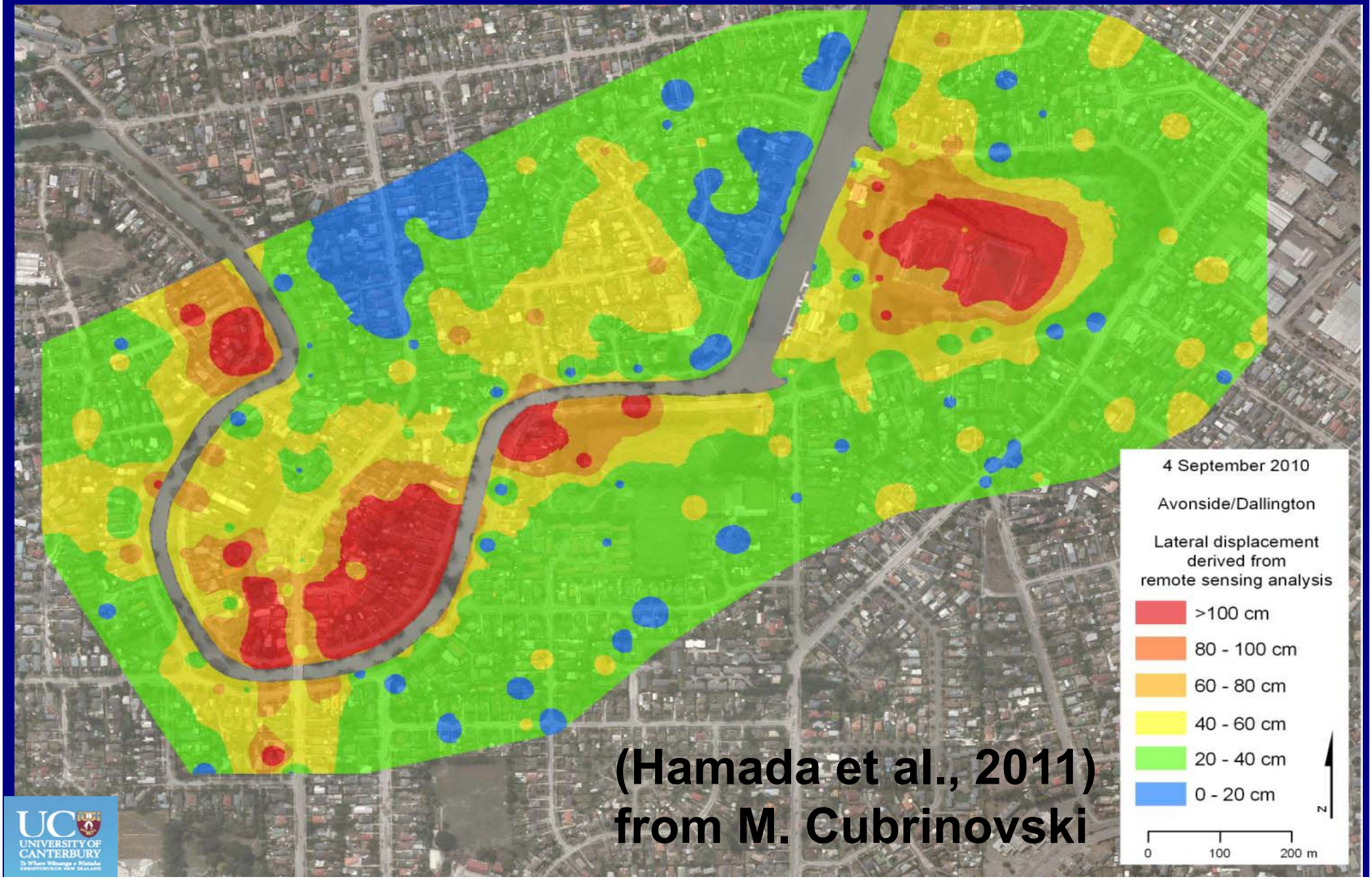
Lateral Spreading: Aerial Photogrammetry



(Hamada et al., 2011)
from M. Cubrinovski

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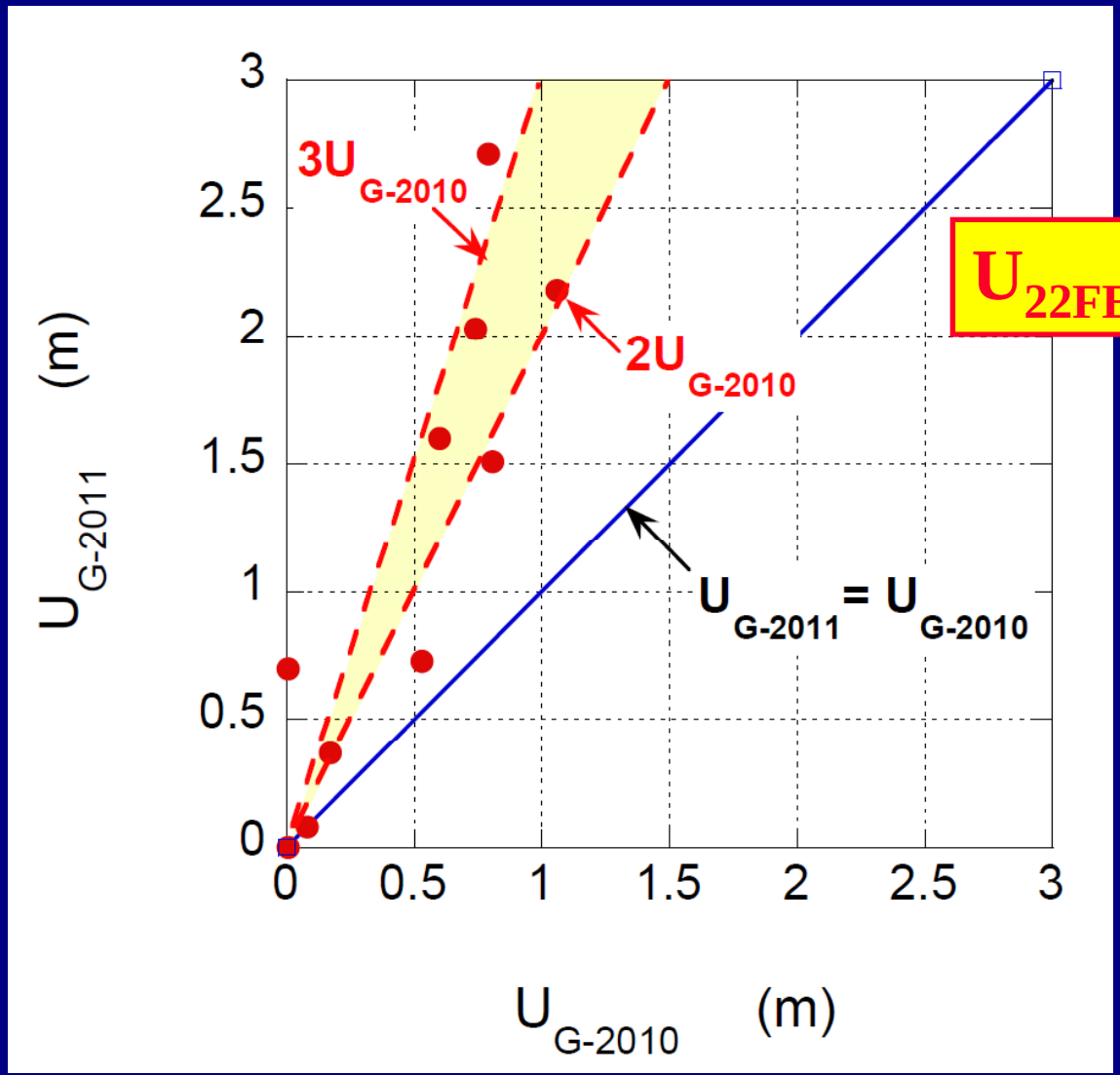
Effects of Lateral Spreading

Lateral Spread Displacements Comparison: 22 Feb 2011 EQ vs. 4 Sep 2010 EQ



$U_{22FEB11}$ = 2 or 3 times U_{4SEP10}

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Liquefaction Effects on Buildings in CBD:

Settlement of Ground Adjacent to Pile Supported Foundation

GEER: Cubrinovski & Bray et al.

Building on Shallow Foundations

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Liquefaction Effects on Buildings:

Uniform Settlement of Ground and Building

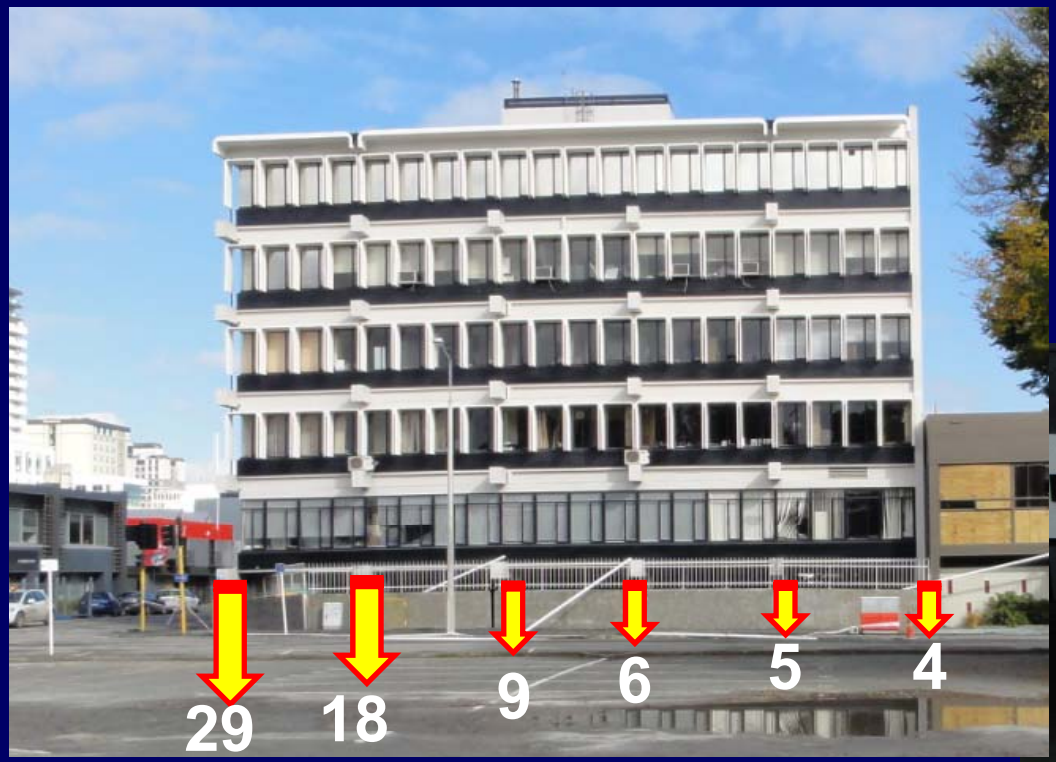
GEER: Cubrinovski & Bray et al.

Liquefaction Effects on Buildings:
Tilting and Differential Settlement

GEER: Cubrinovski & Bray et al.

Liquefaction Effects on Buildings:

Differential Settlement of Adjacent Columns Induces Distress



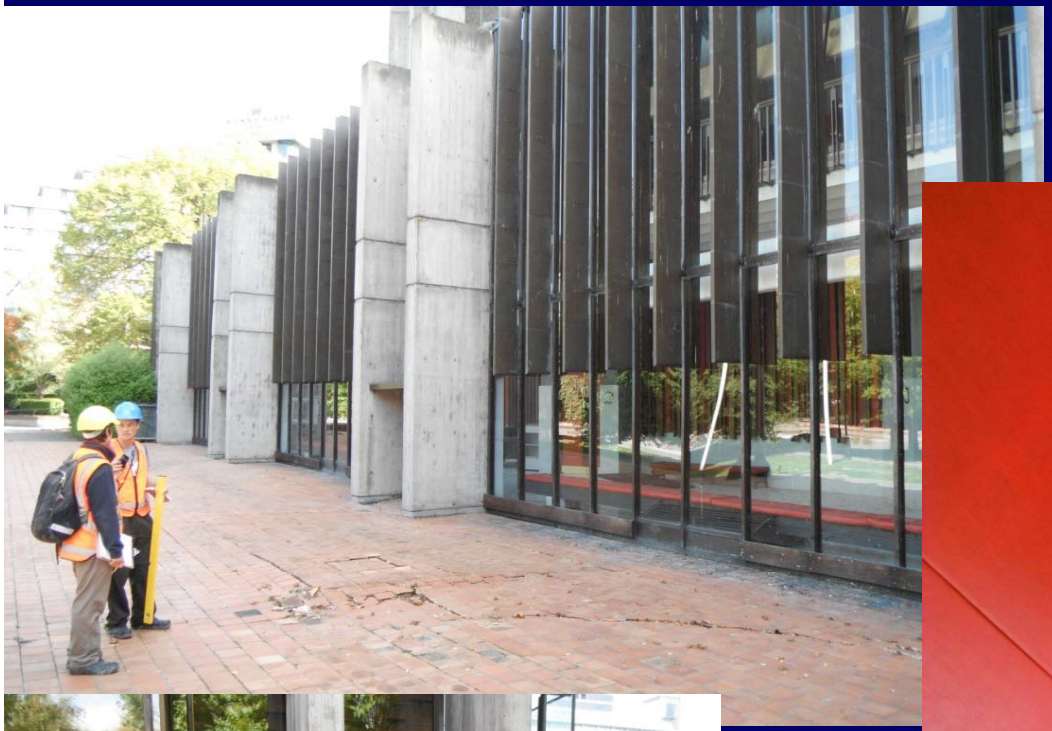
Building Settlement (cm)

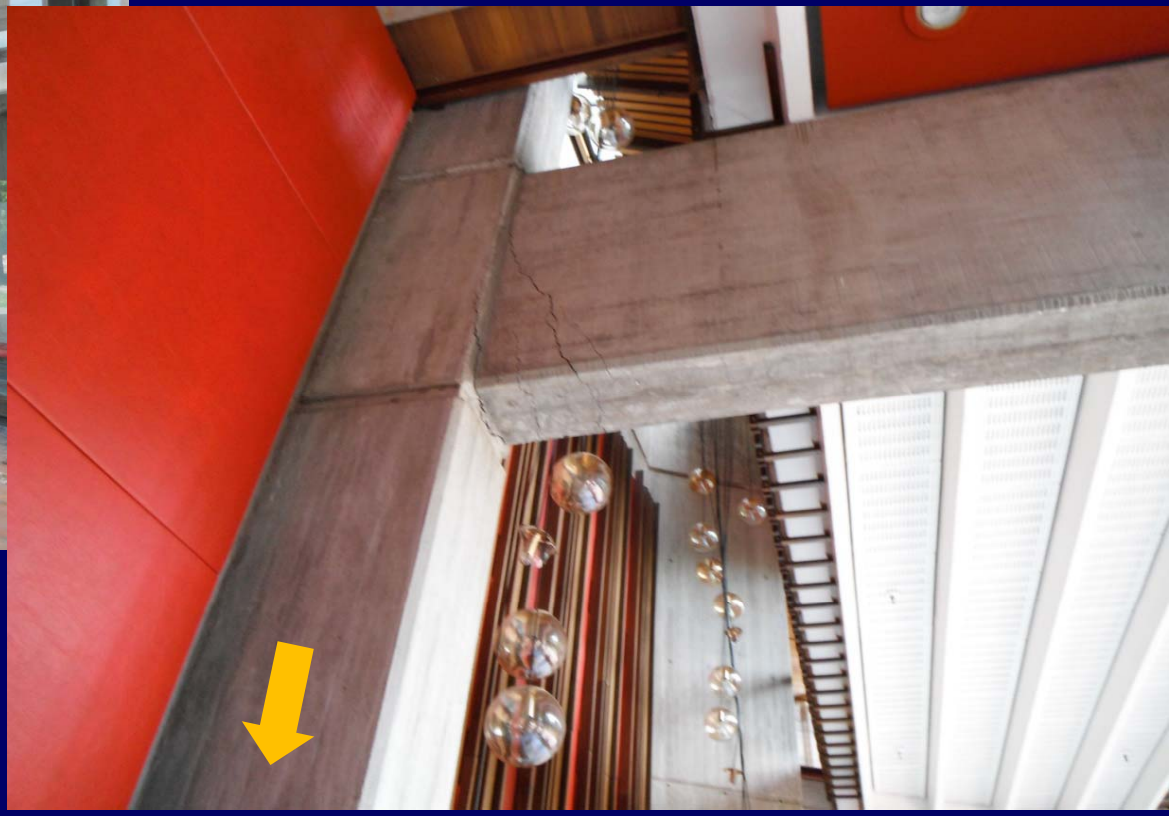
Maximum Angular Distortion ≈ 1 / 50

GEER: Cubrinovski & Bray et al.

Liquefaction Effects on Buildings:

Differential Settlement of Adjacent Columns Induces Distress





Angular distortion of 1 / 70

GEER: Cubrinovski & Bray et al.

Tilting and Sliding of Buildings

Tilting of Tall Buildings

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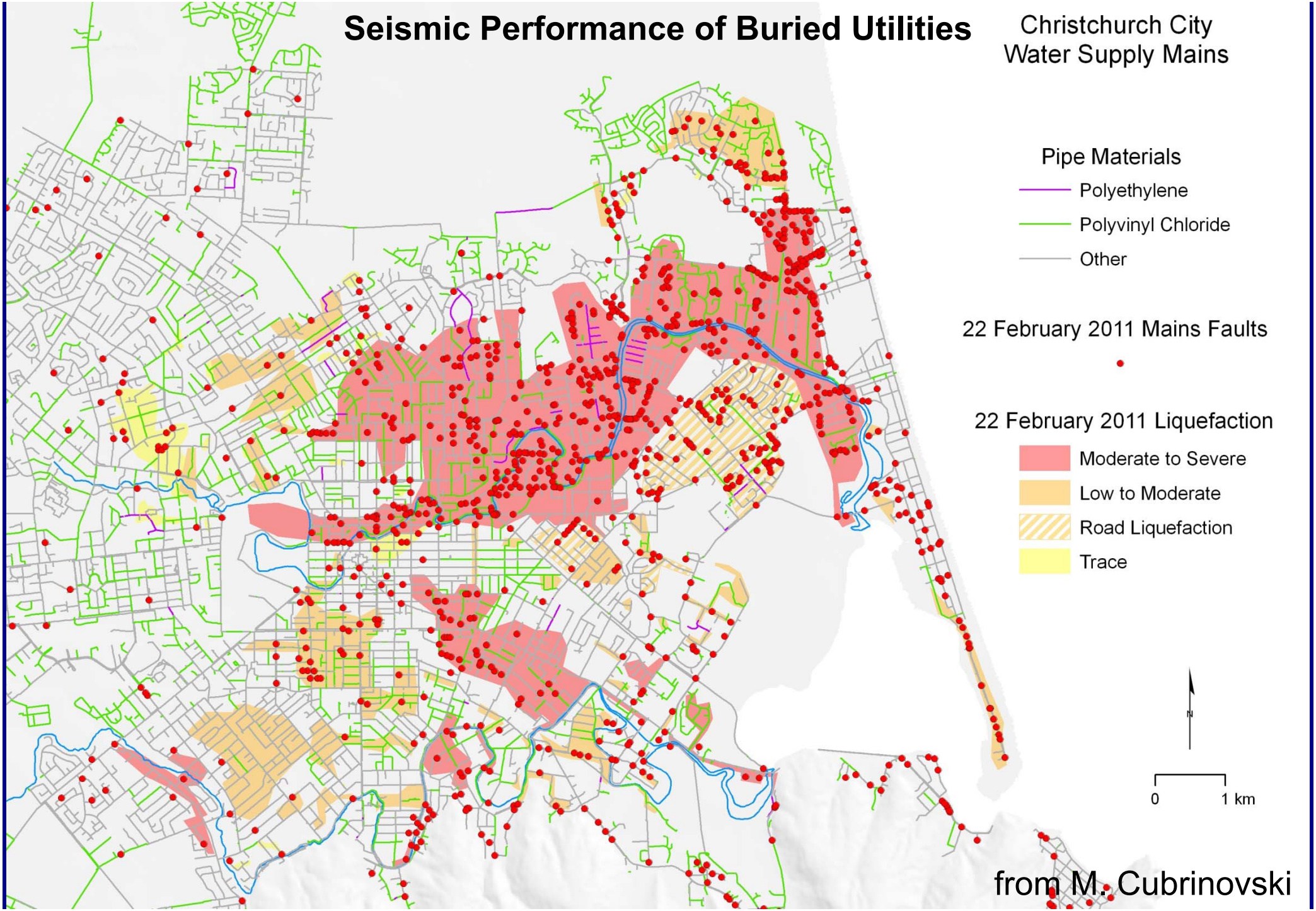
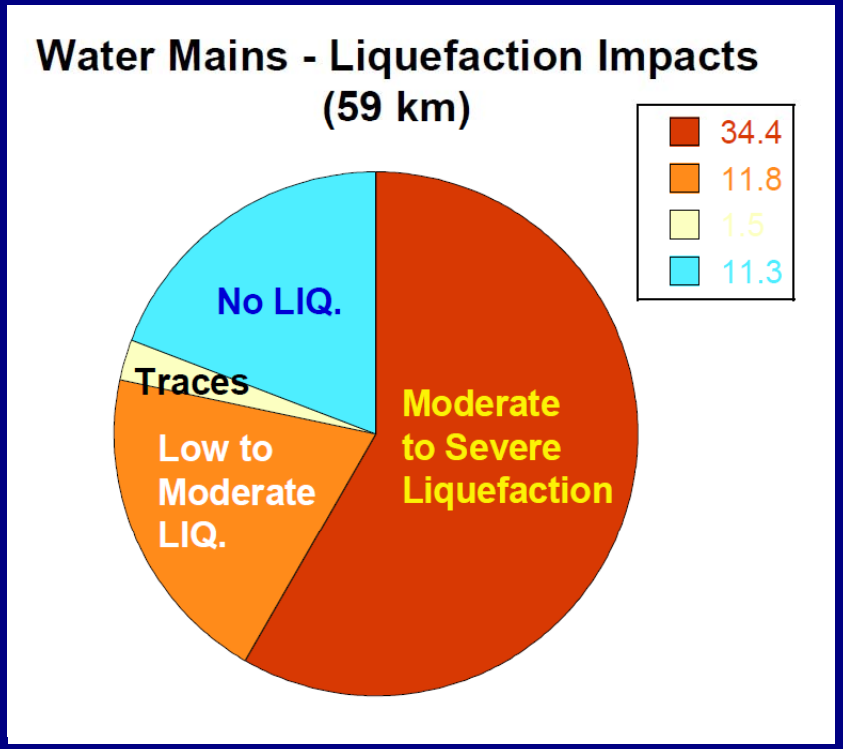
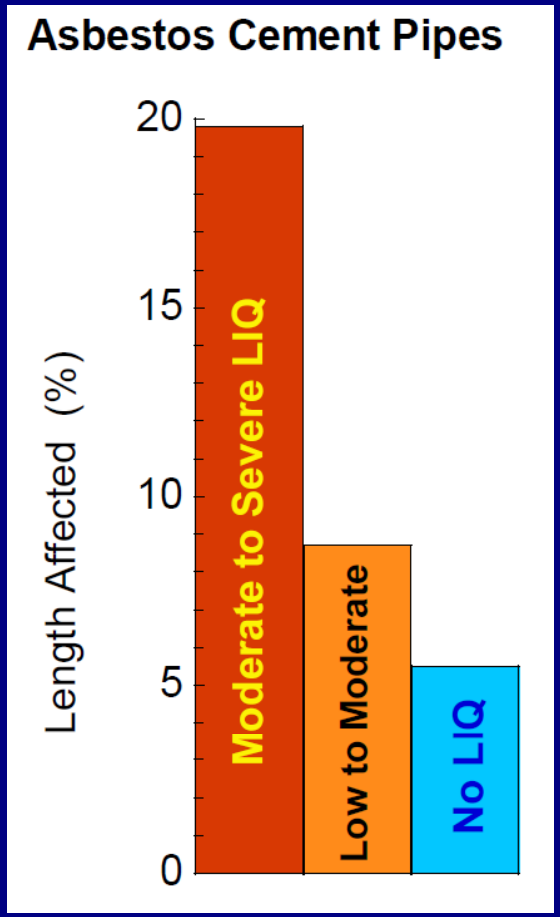
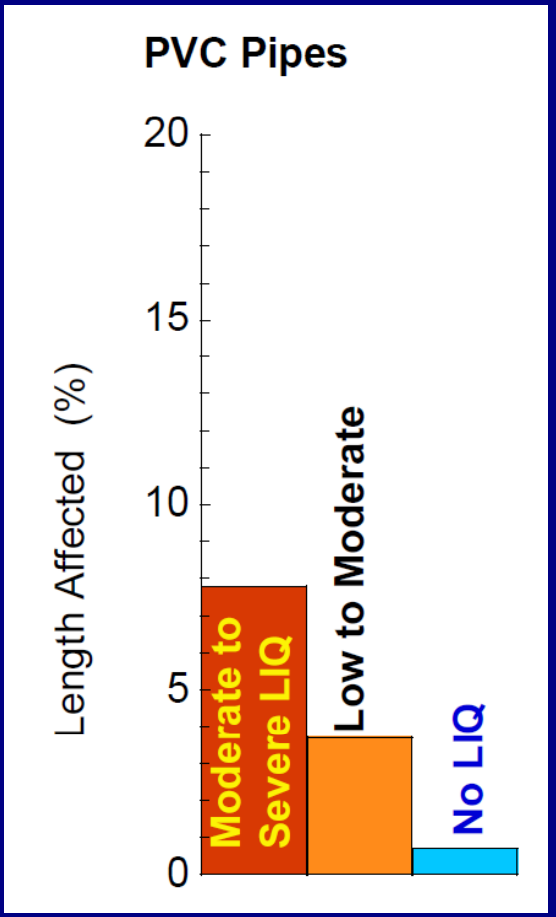

Seismic Performance of Buried Utilities
Christchurch City
Water Supply Mains
Pipe Materials
Polyethylene
Polyvinyl Chloride
Other
22 February 2011 Mains Faults
22 February 2011 Liquefaction
Moderate to Severe
Low to Moderate
Road Liquefaction
Trace
N
0
1 km
from M. Cubrinovski

Effects of Liquefaction on Water Mains







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Conclusions

- Liquefaction occurred in some places in 3 of the EQs
- Each event was well recorded by strong motion stations, so there is an opportunity to refine the Magnitude Scaling Factor
- At times, liquefaction severely damaged the ground, buildings, and buried utilities
- Liquefaction destroyed some suburbs to the point where they will be abandoned
- Liquefaction effects in the CBD along Avon River were dramatic: the “heart” of the city is still broken

Acknowledgements

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