Canterbury Earthquakes Royal Commission Hearings
25 October 2011, Christchurch

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Foundations on Deep Alluvial Soils

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Geotechnical Considerations

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- A general review of the alluvial soils found in the CBD
- Their performance and effects in the recent Canterbury earthquake sequence
- Liquefaction and lateral spreading
- The general concepts that should be followed in the design of foundations for buildings on deep alluvial soils.

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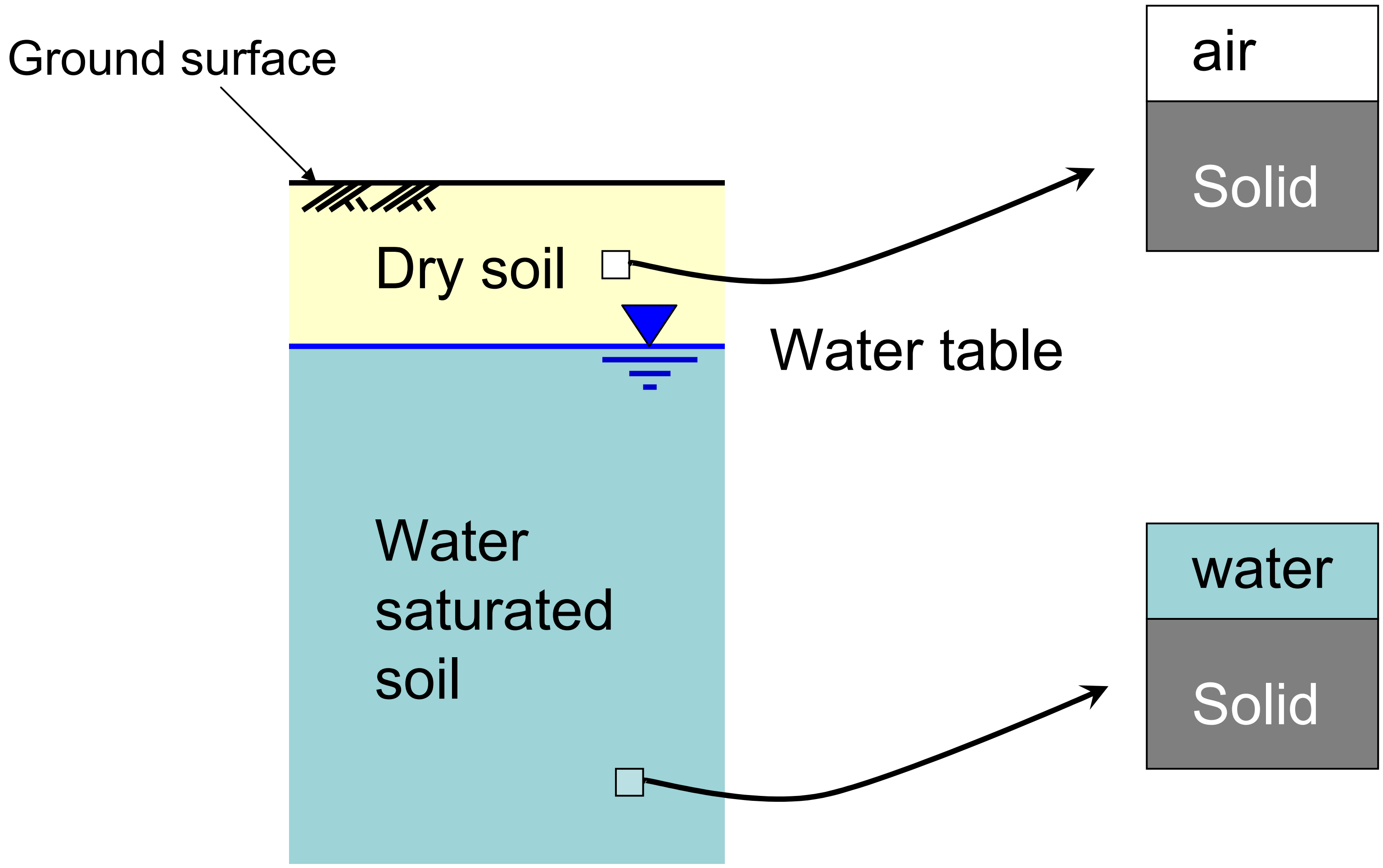
Outline

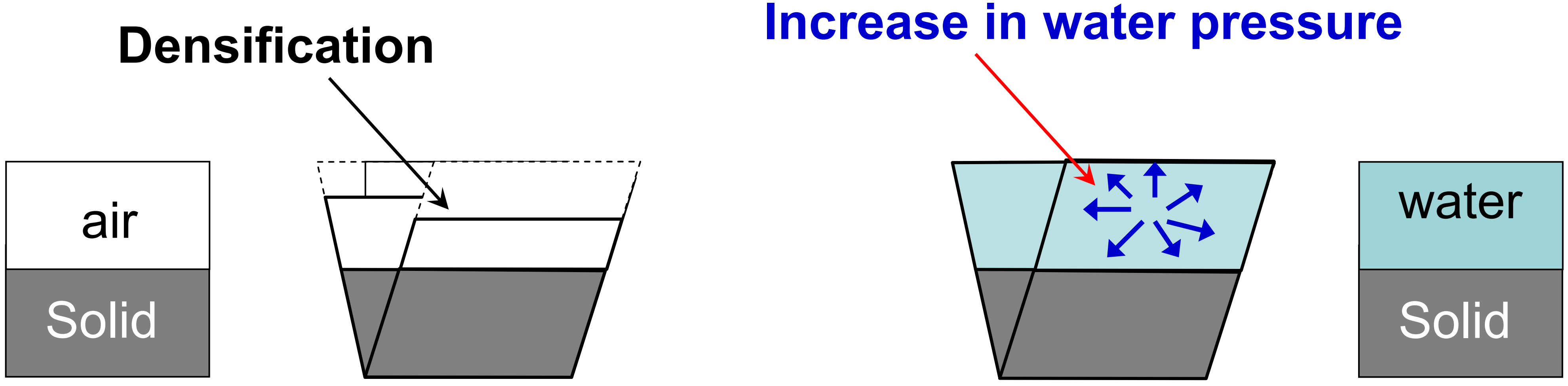
1. Seismic response of deep alluvial soils *(general features)*
2. Christchurch CBD Soils
3. Observed liquefaction and response spectra *(2010-2011 earthquakes)*
4. Typical causes of *'failure'* in the CBD
5. Comparison of extent of liquefaction between 2010-2011 earthquakes and a M_W=8 Alpine Fault earthquake
6. Typical foundation methods that would avoid such failures

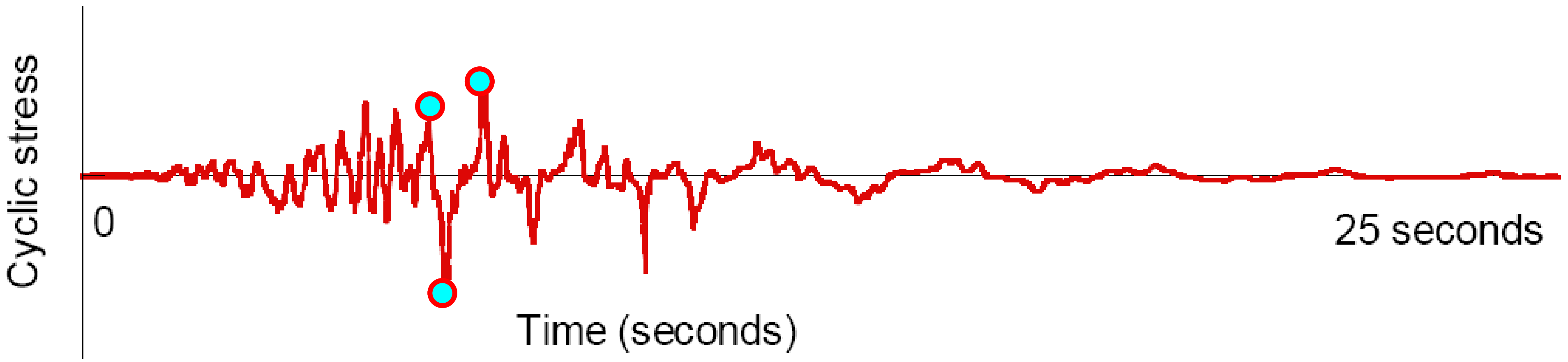
Soil Liquefaction

Groundwater (water saturated soils)



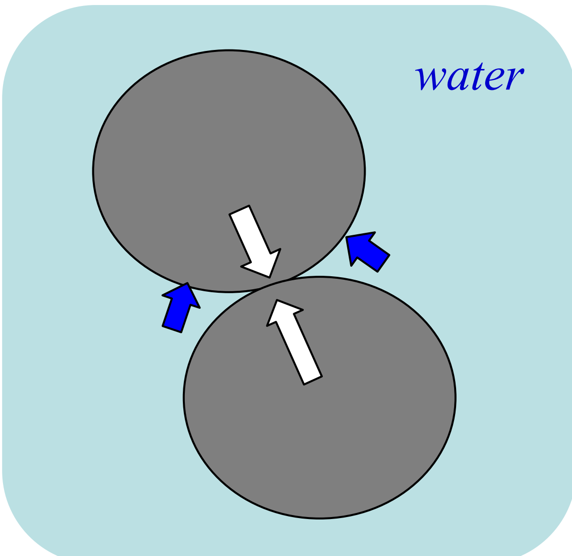
When shaken by an earthquake





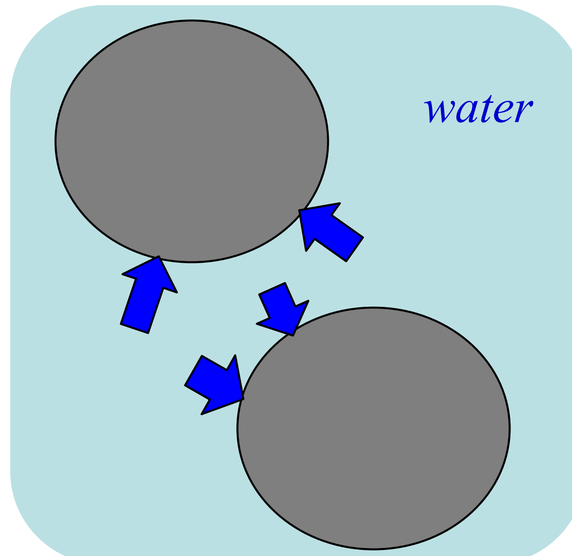
Groundwater Pressure and Liquefaction

Particles in a stable state



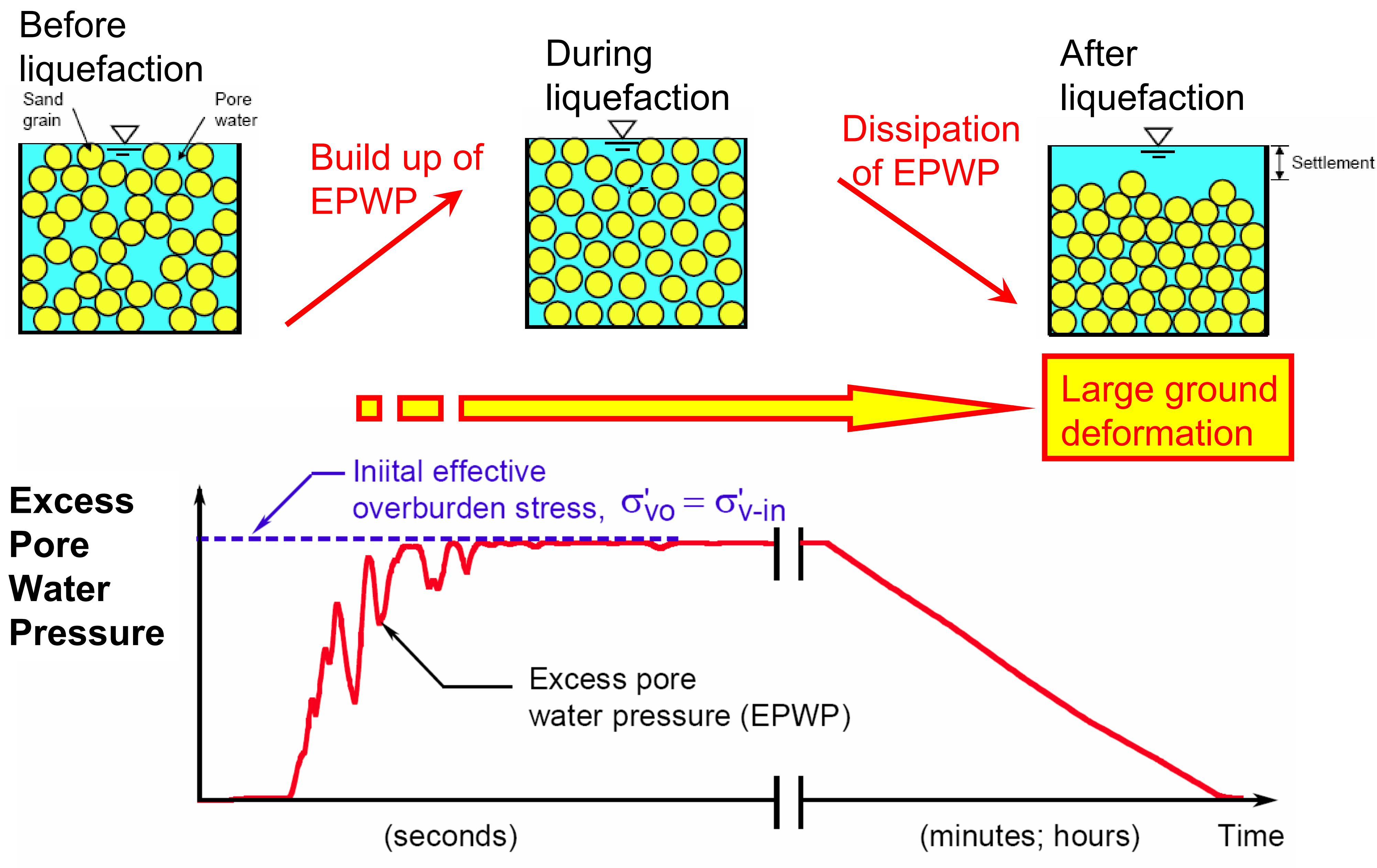
(low groundwater pressure)

Unstable state = LIQUEFACTION
(particles in suspension)

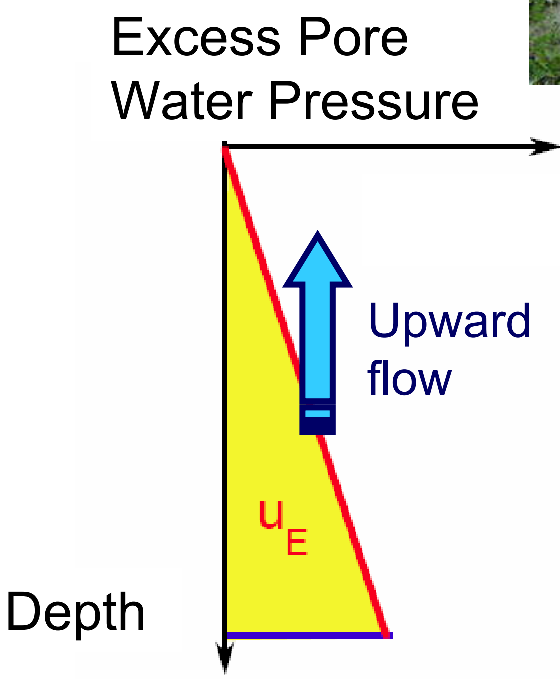


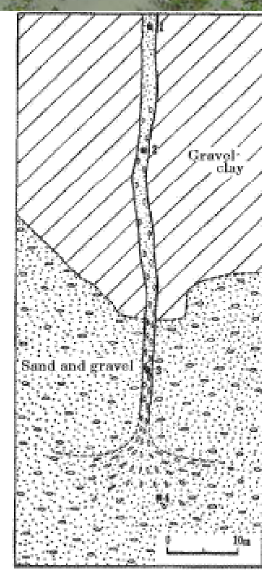
(high groundwater pressure)

Liquefaction during Earthquakes

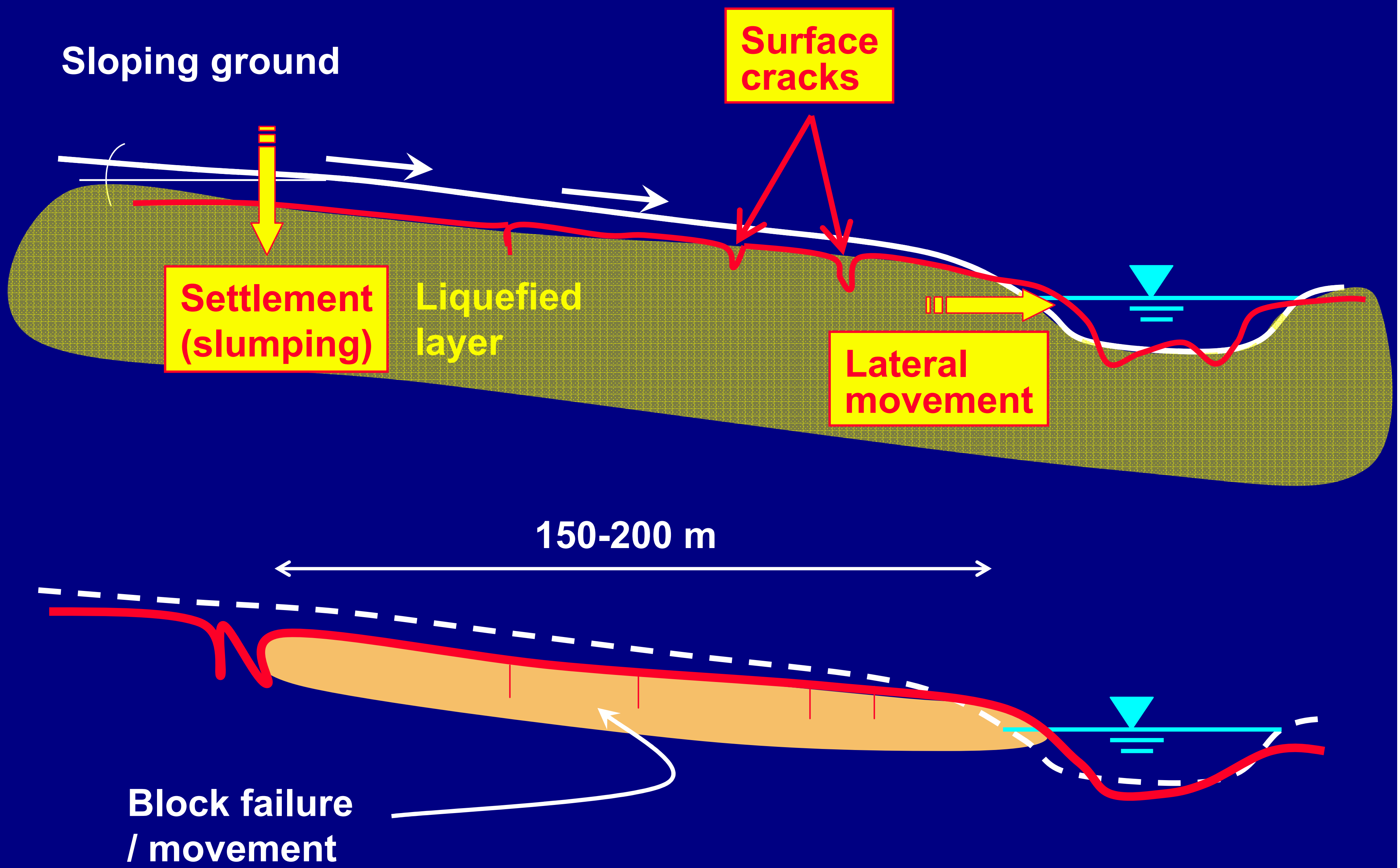


Upward Water Flow and 'Sand Volcanoes'





Lateral Spreading Mechanism

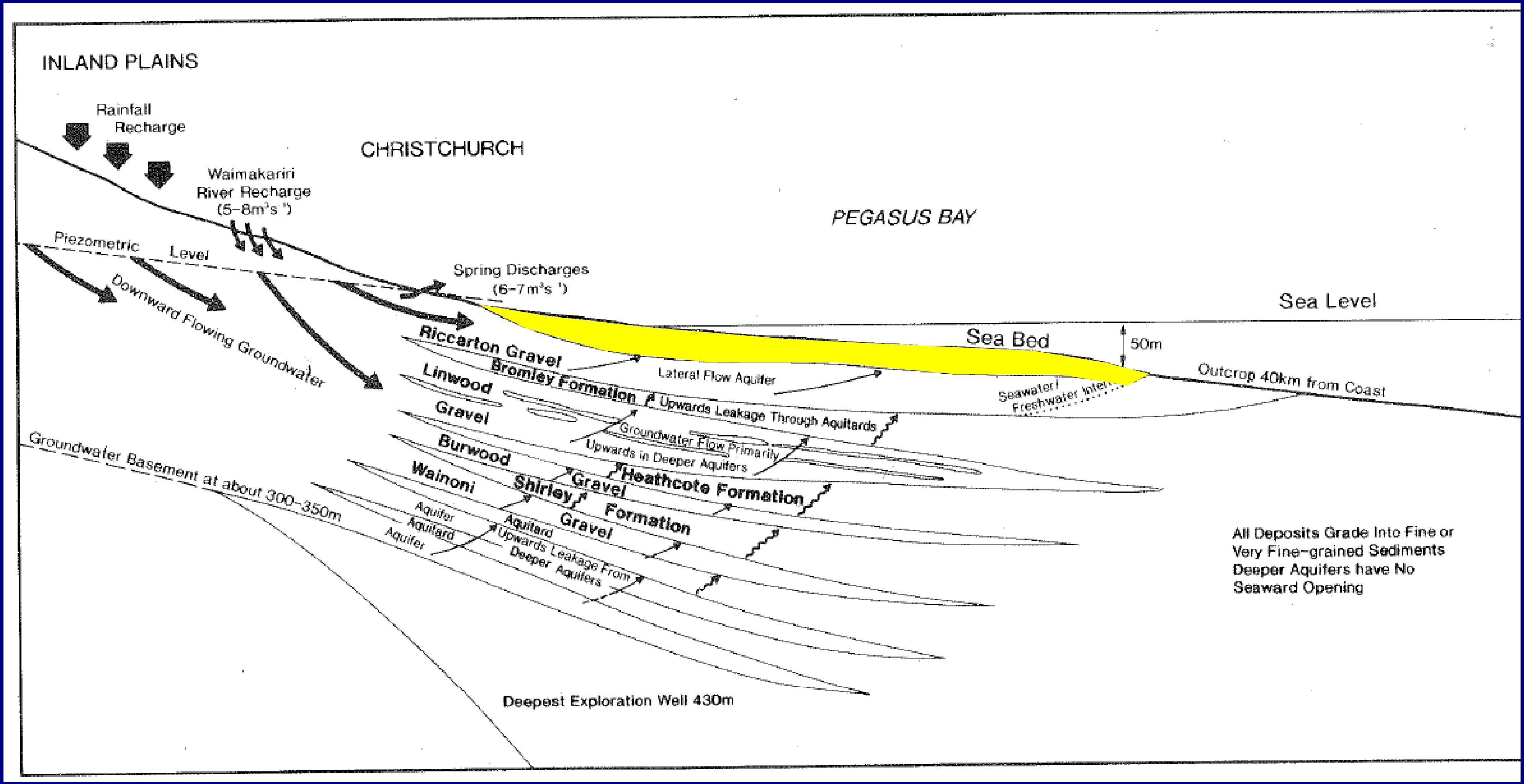


Liquefaction Evaluation Procedure

1. Liquefaction susceptibility *(Are the soils at the site liquefiable or not?)*
2. Liquefaction triggering *(Are the soils going to liquefy when shaken by the design earthquake?)*
3. Liquefaction-induced ground deformation *(What will be the consequences of liquefaction in terms of ground deformation and land damage?)*
4. Impacts of liquefaction on building foundations *(What will be the impact of liquefaction on foundations/structures?)*
5. Countermeasures against liquefaction *(How to prevent liquefaction from occurring or reduce its impacts on structures?)*

Christchurch CBD Soils

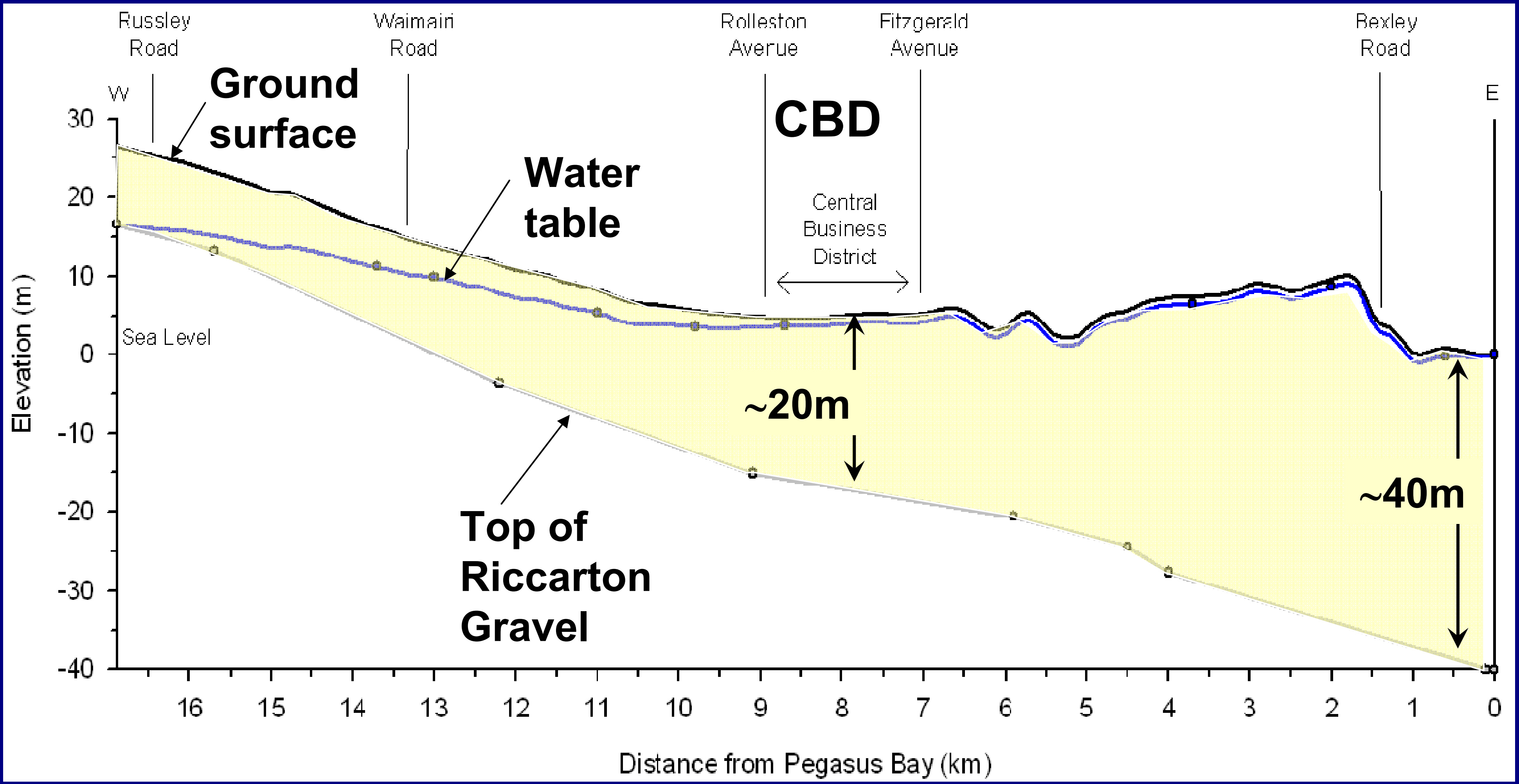
Canterbury Plains at Christchurch



(Figure 2)

After Brown and Weeber (1992)

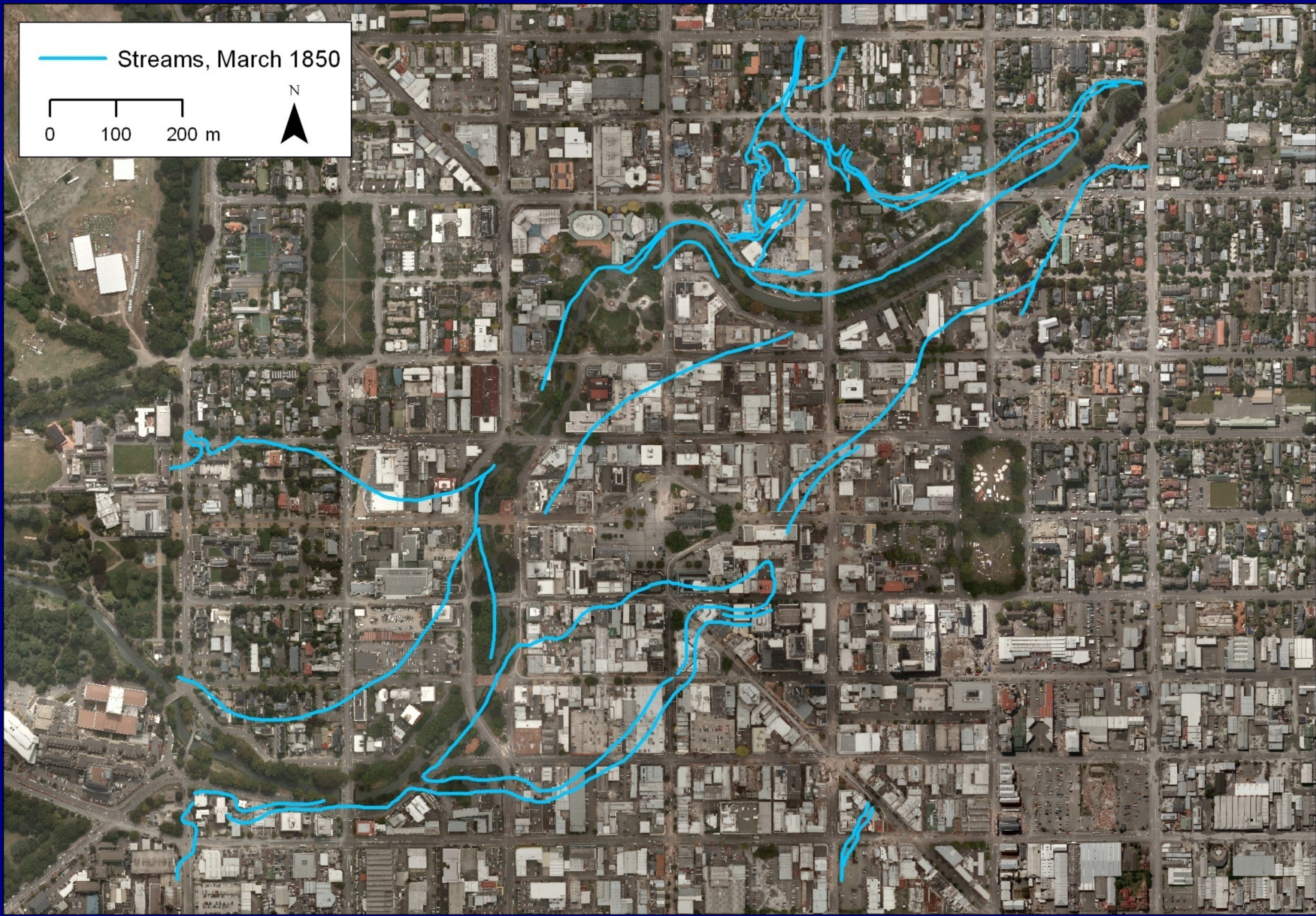
East-West Cross Section



(Figure 3a)

Cross section along the direction of Bealey Avenue (Cubrinovski and McCahon, 2011)
Data from Landcare Research (2011) and Brown and Weeber (1992)

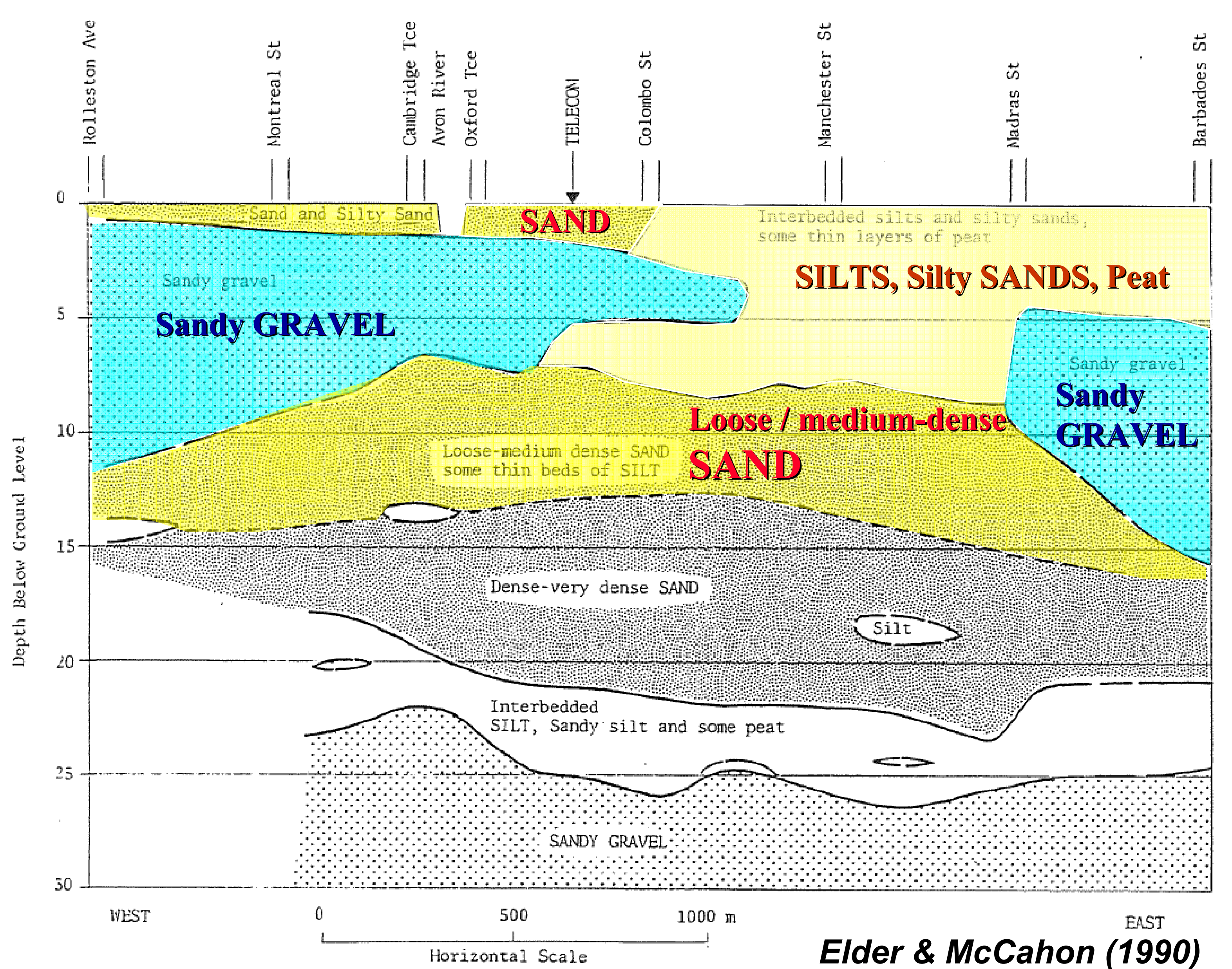
Streams in Central Christchurch in the 1850



(Figure 4)

('Black Maps')

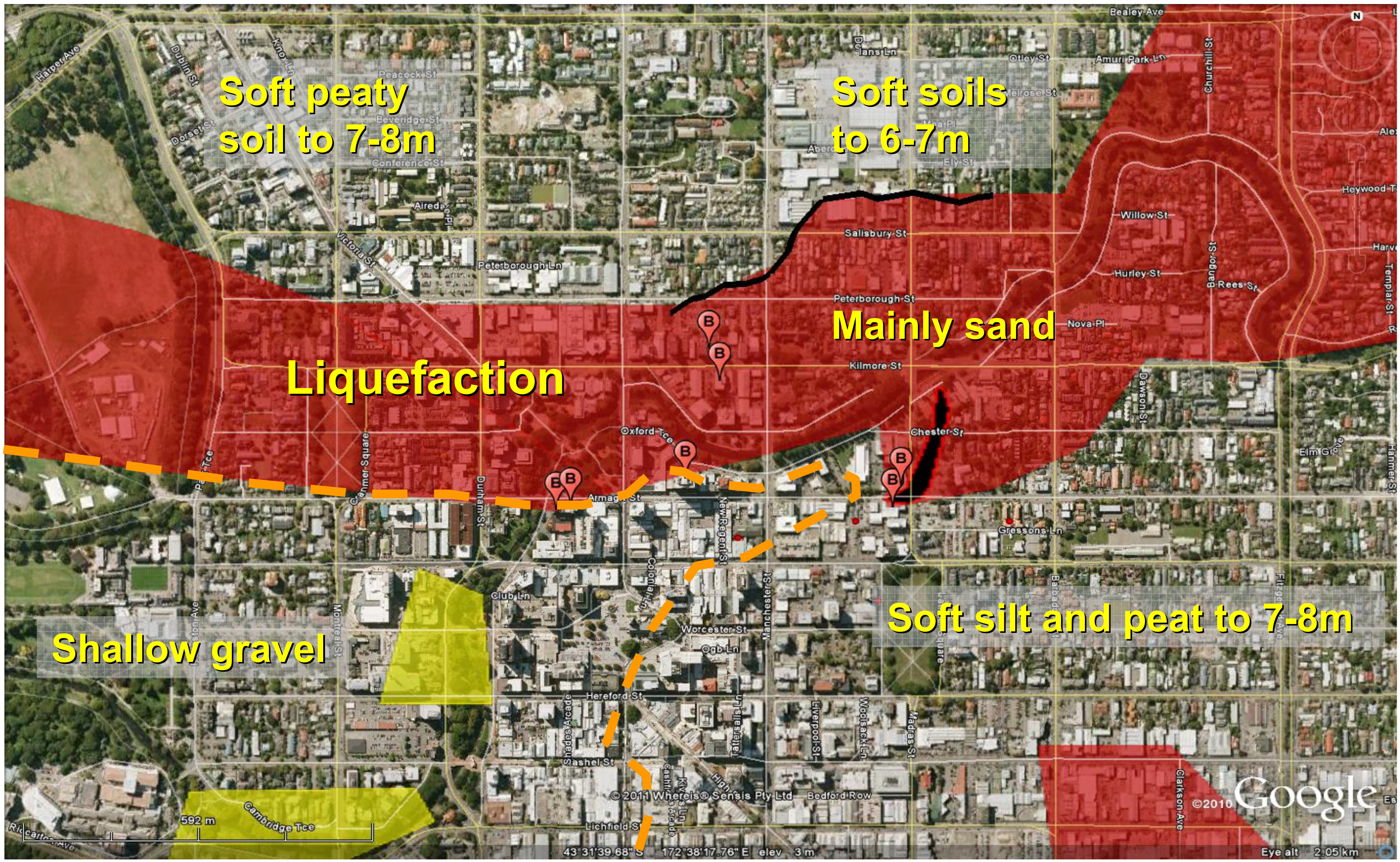
Hereford Street Soil Profile



Elder & McCahon (1990)

(Figure 5)

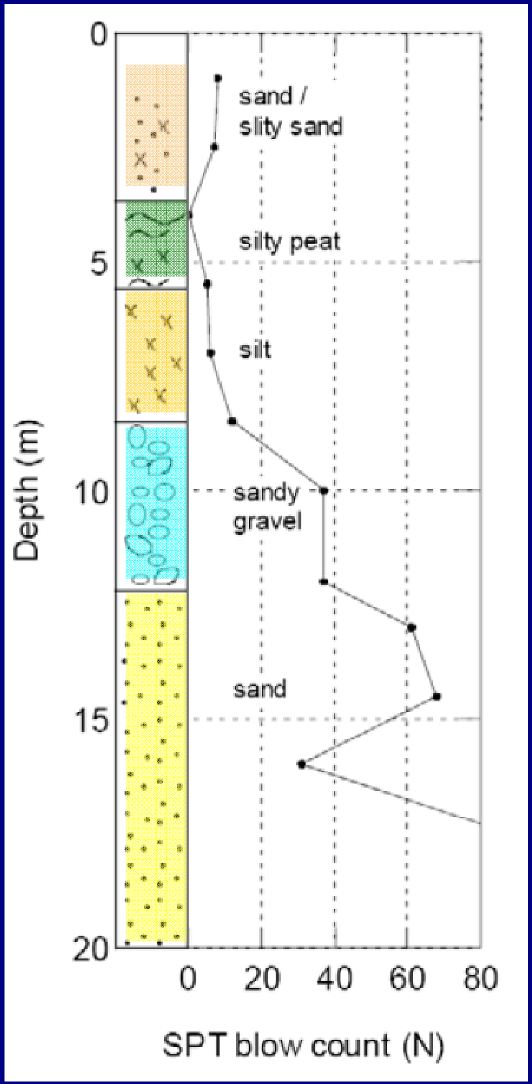
CBD Liquefaction Map



(Figure 6)

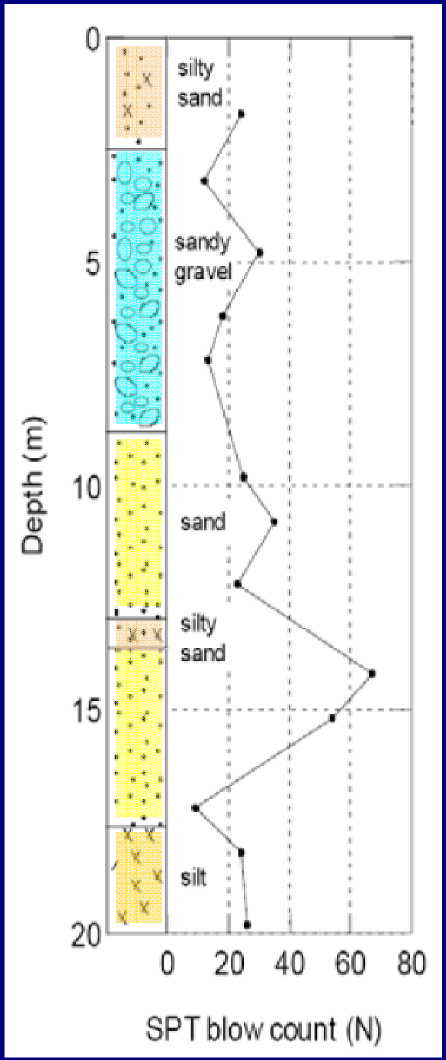
Drive through reconnaissance map (Cubrinovski and Taylor, 2011)

Characteristic Soil Profiles (1)



(Figure 7a)

North-west part of the CBD

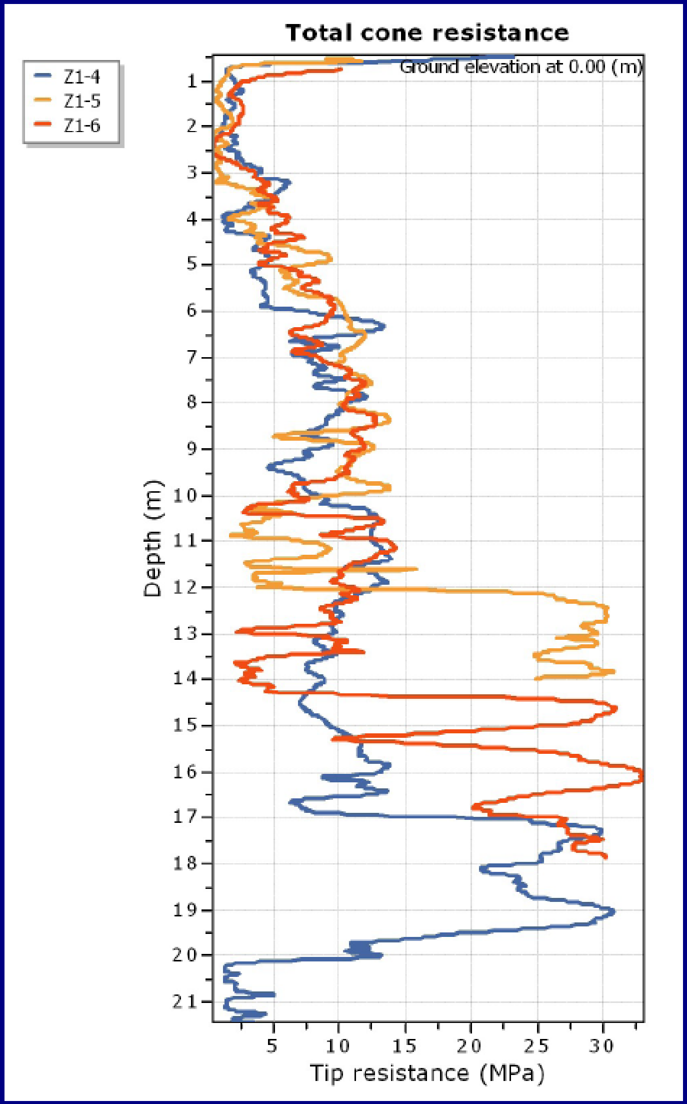


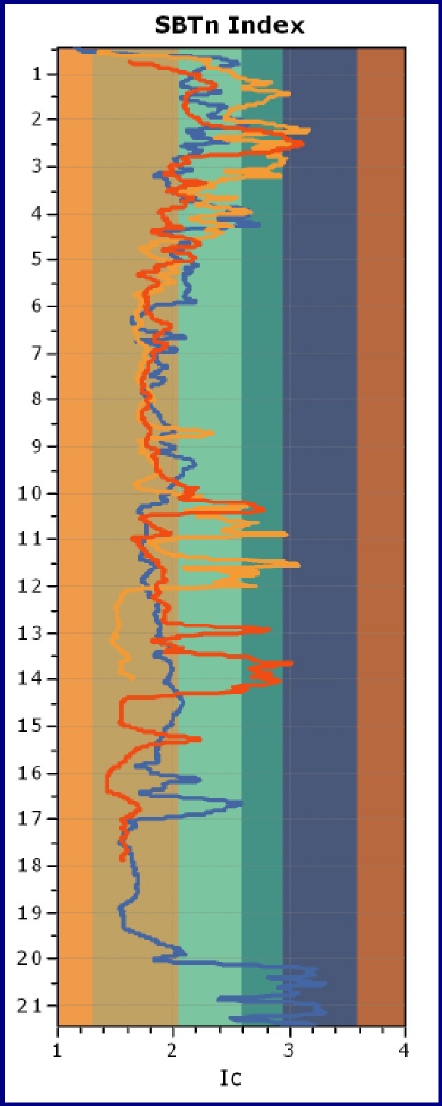
(Figure 7b)

South-west part of the CBD

GEO.CUB.0001.1-35.19

Characteristic Soil Profiles (2)

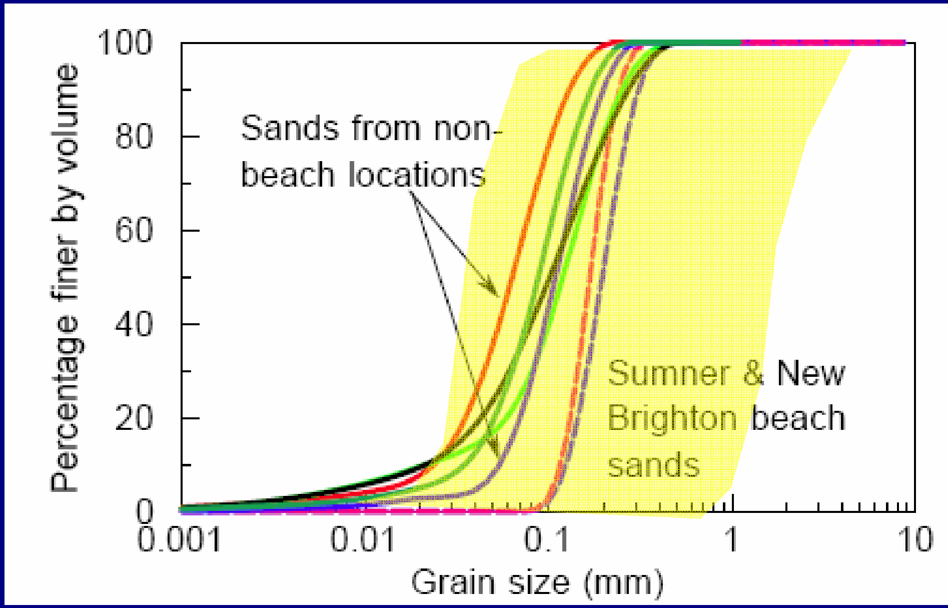




East-west trending zone of liquefaction within CBD

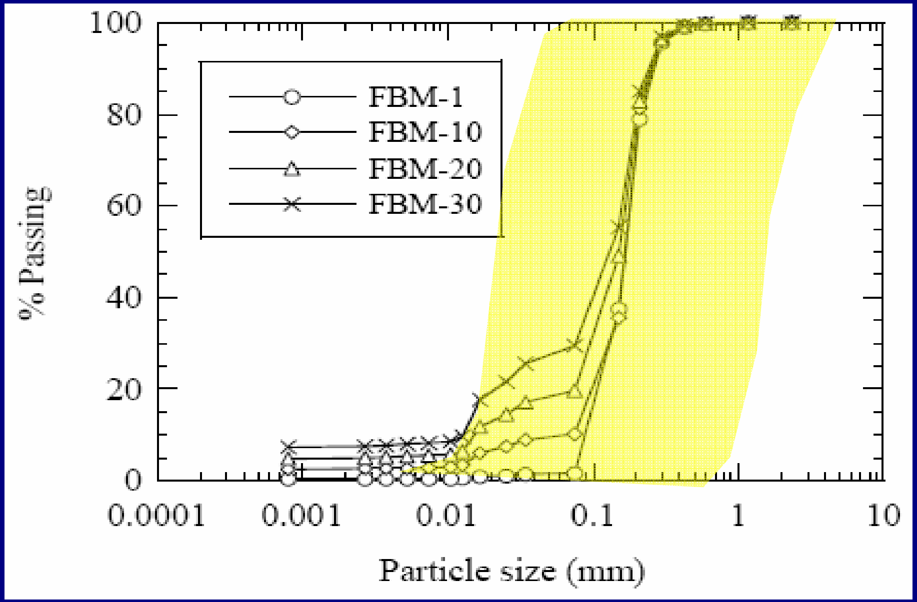
Grain-size Composition of Soils

Sand ejecta samples



(courtesy of Michael Pender)

Fitzgerald Bridge samples



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

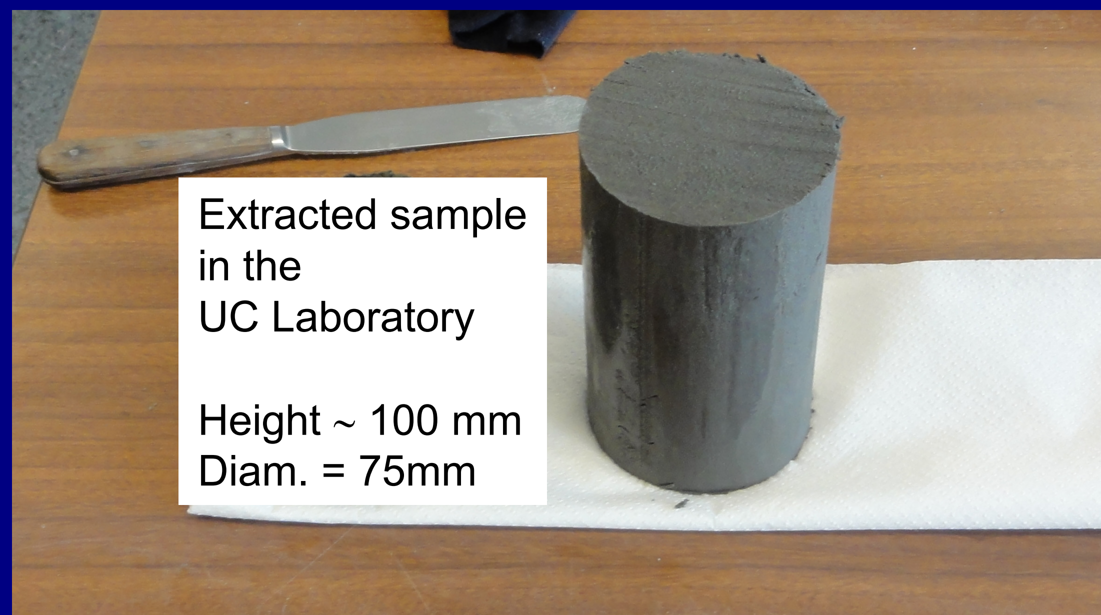
- **Clean sands and sands with non-plastic silts**

CBD Gel-Push Sampling

(July-August 2011)

GP Sampling
(CBD site)

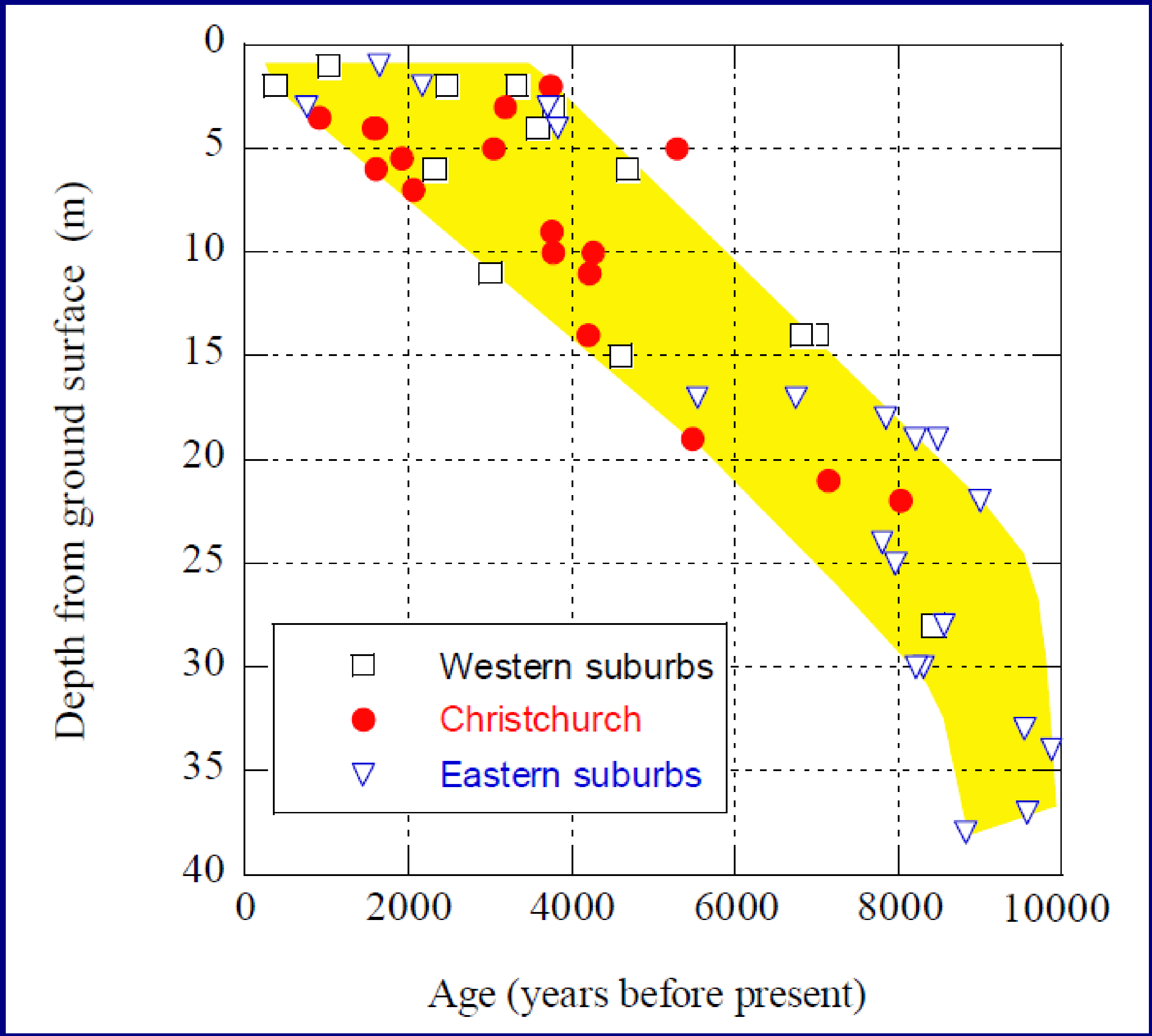
GP Sample
in the field
(in a tube)



Extracted sample
in the
UC Laboratory

Height ~ 100 mm
Diam. = 75mm

Age of Soils



(Figure 8)

Cubrinovski and McCahon (2011); data from Brown and Weeber (1992)

Summary on CBD Soils

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- The top 20-25 m of the CBD are relatively recent alluvial soils overlying 300 m to 500 m thick gravelly deposits

- Recent river, swamp and marine sediments in the top 20 m (gravels, sands, silts, peat and their mixtures; highly variable)
- In some areas sands and non-plastic silts deposited in a (very) loose state
- High water table (fully saturated soils below 1.0 m to 1.5 m depth)
- Relatively young soils (few hundreds to a few thousand years old)

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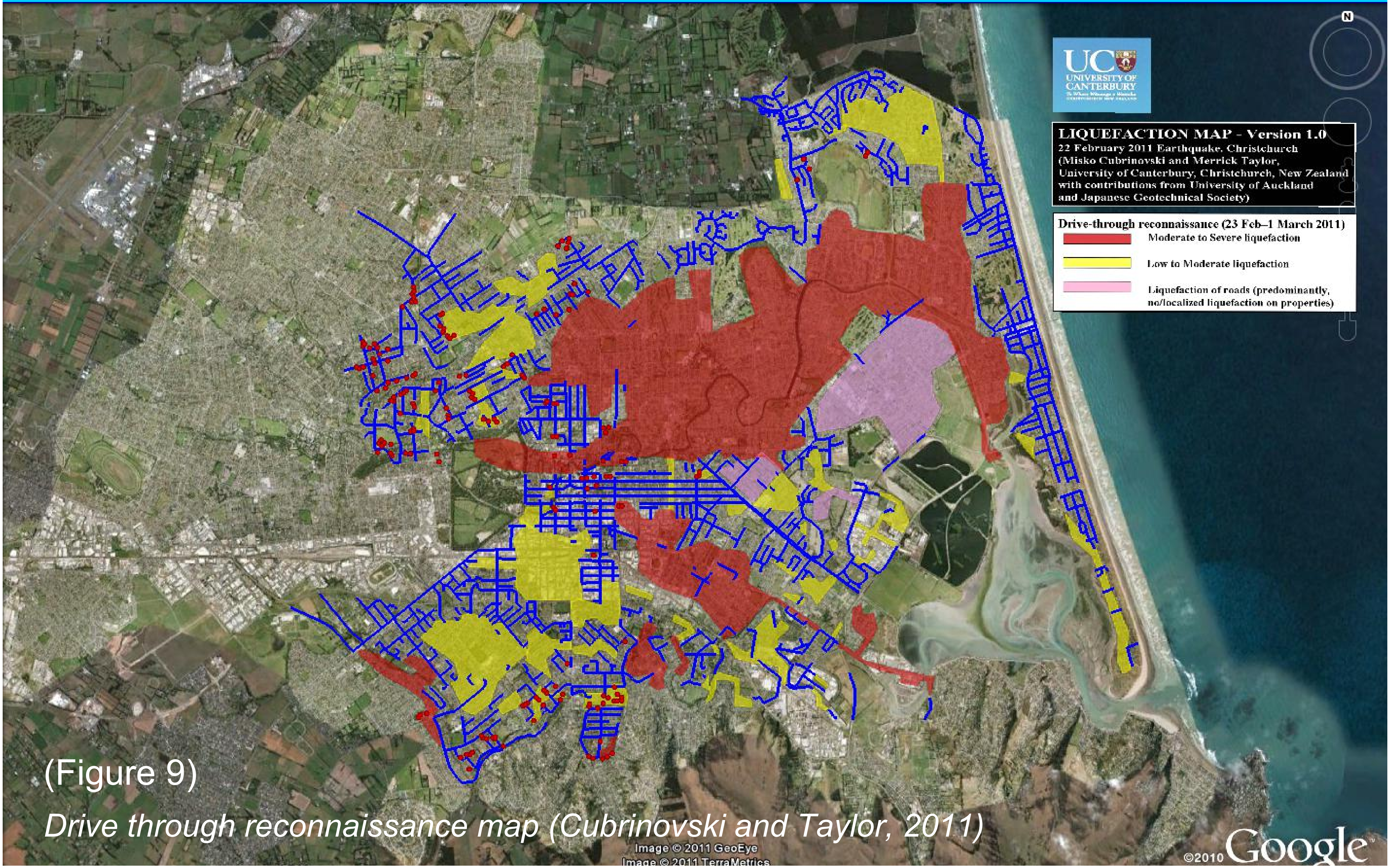
HIGH LIQUEFACTION POTENTIAL

- Complex foundation conditions
- The role of artesian aquifers (?)

Observed Liquefaction and Response Spectra

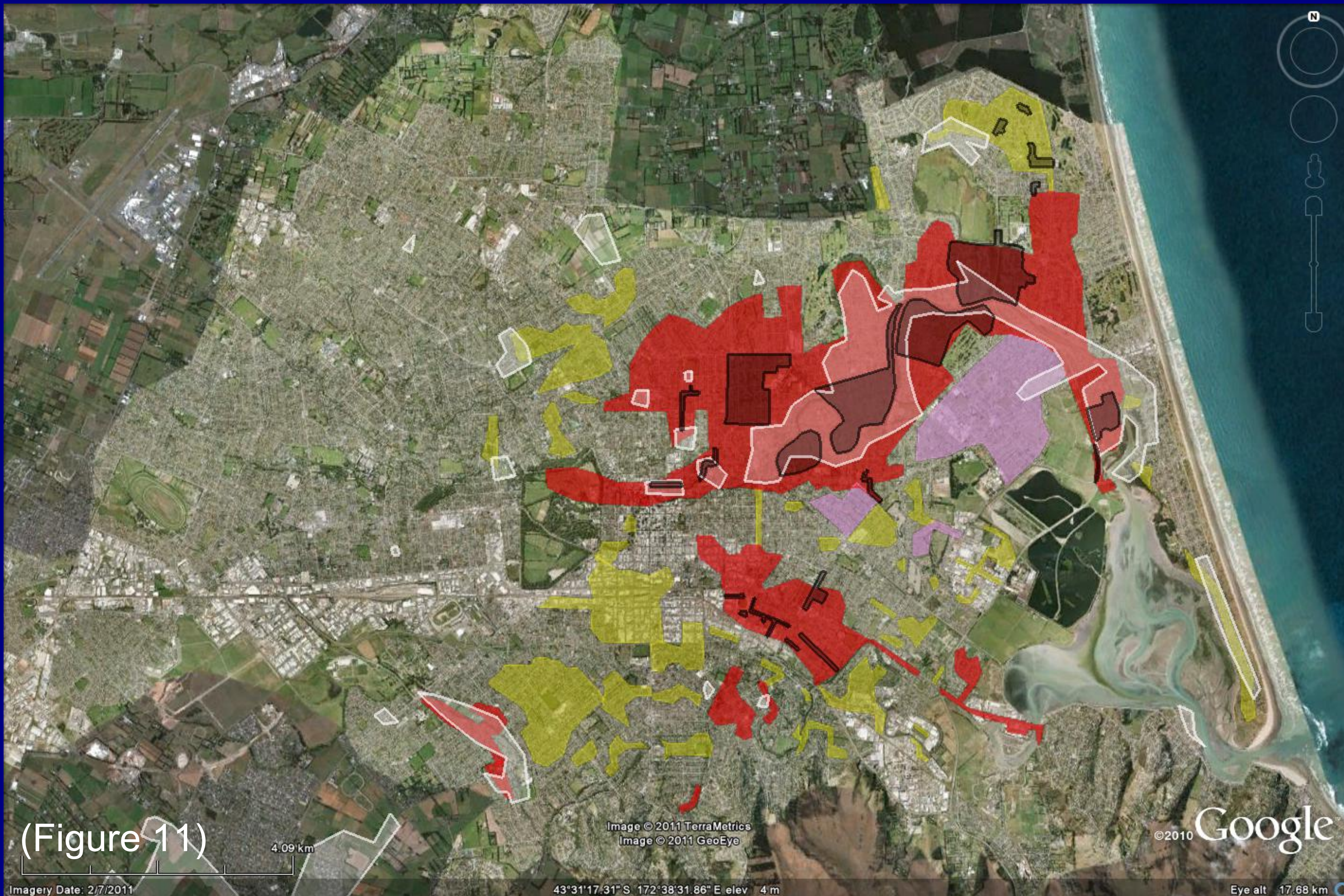
Liquefaction Map: February 2011 Earthquake



(Figure 9)

Drive through reconnaissance map (Cubrinovski and Taylor, 2011)

Liquefaction Maps from Three Earthquakes



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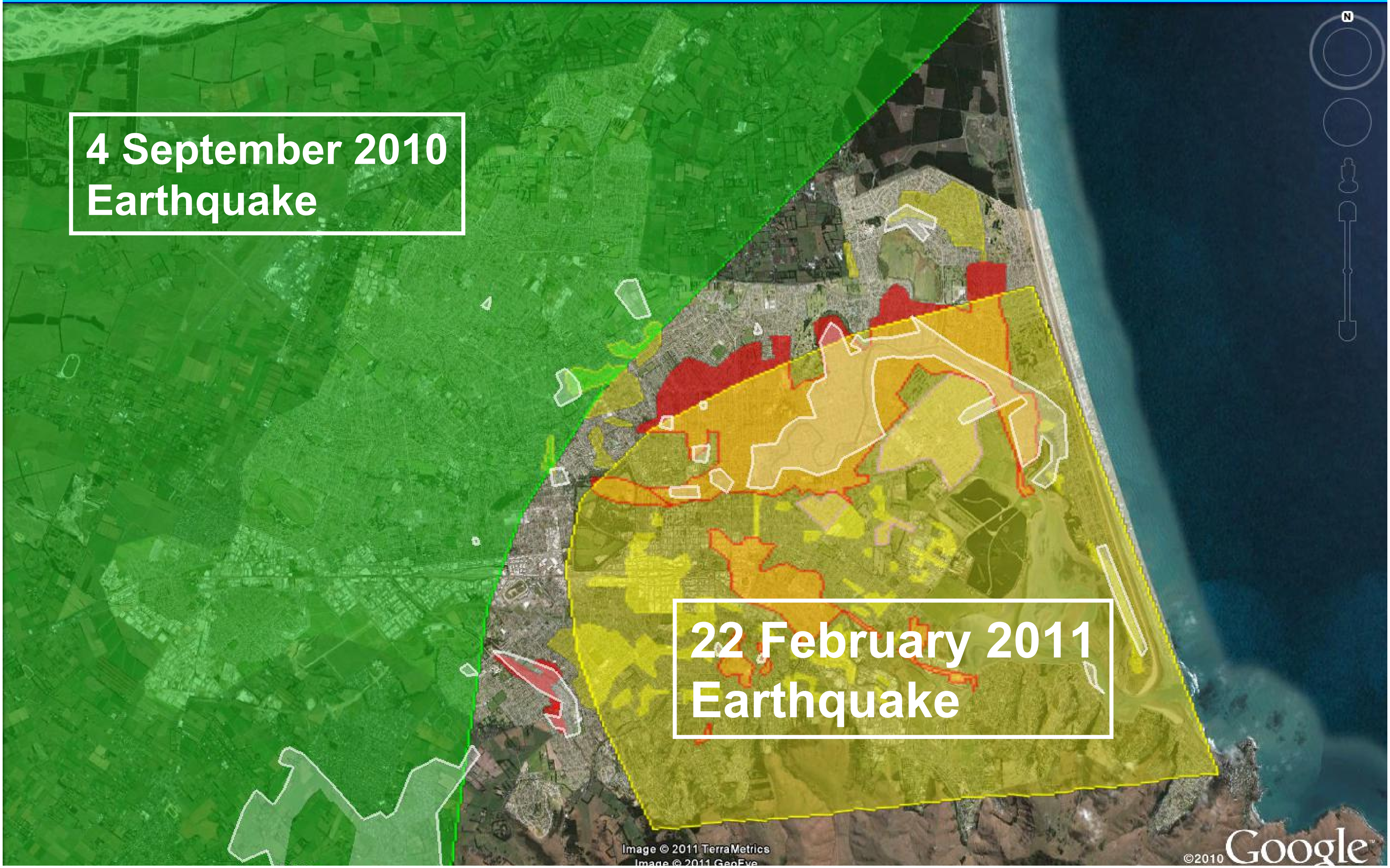
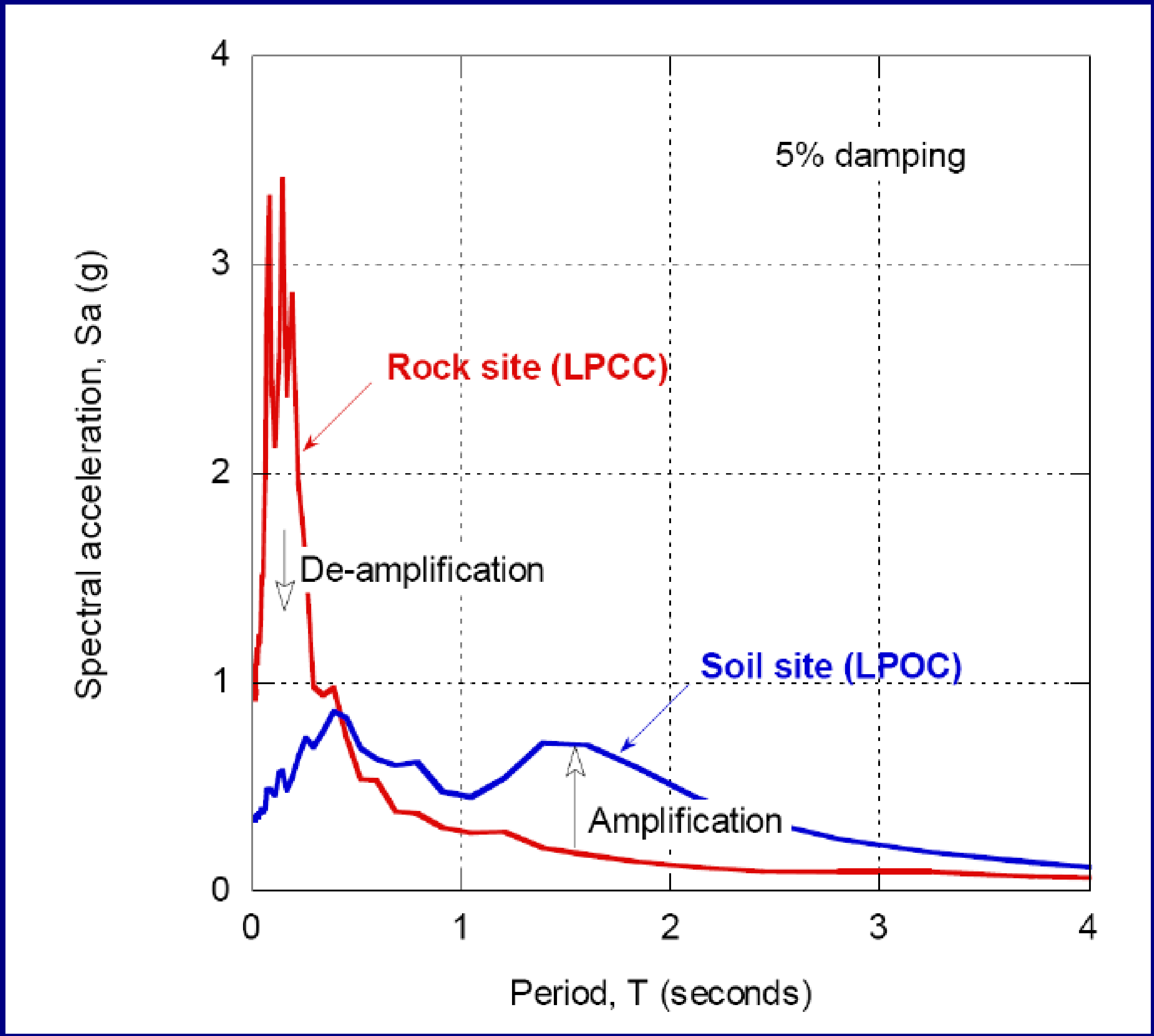
Dominant Earthquake Event

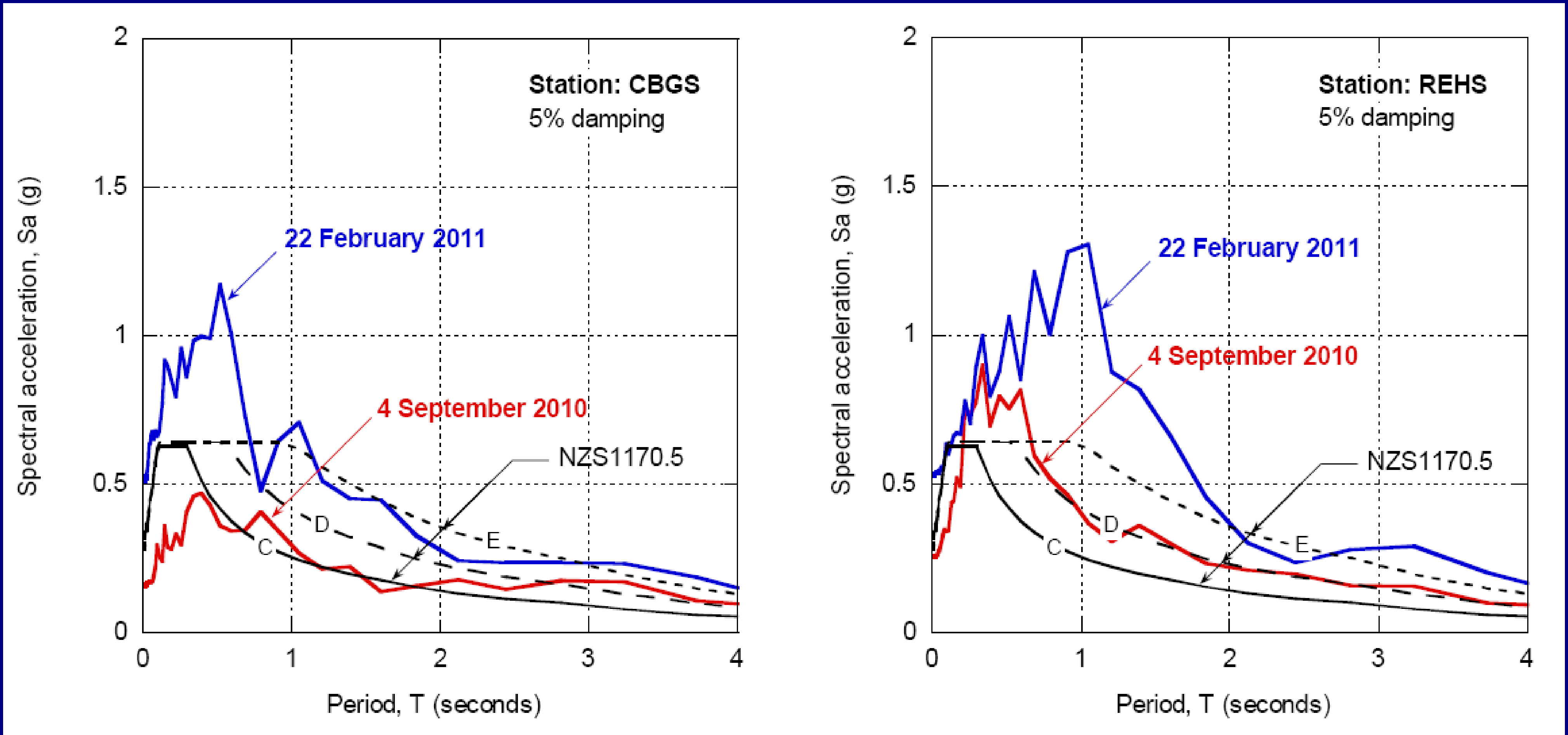


Effects of Soil Conditions on Response Spectra



(Figure 12)

CBD Response Spectra



(Figure 14)

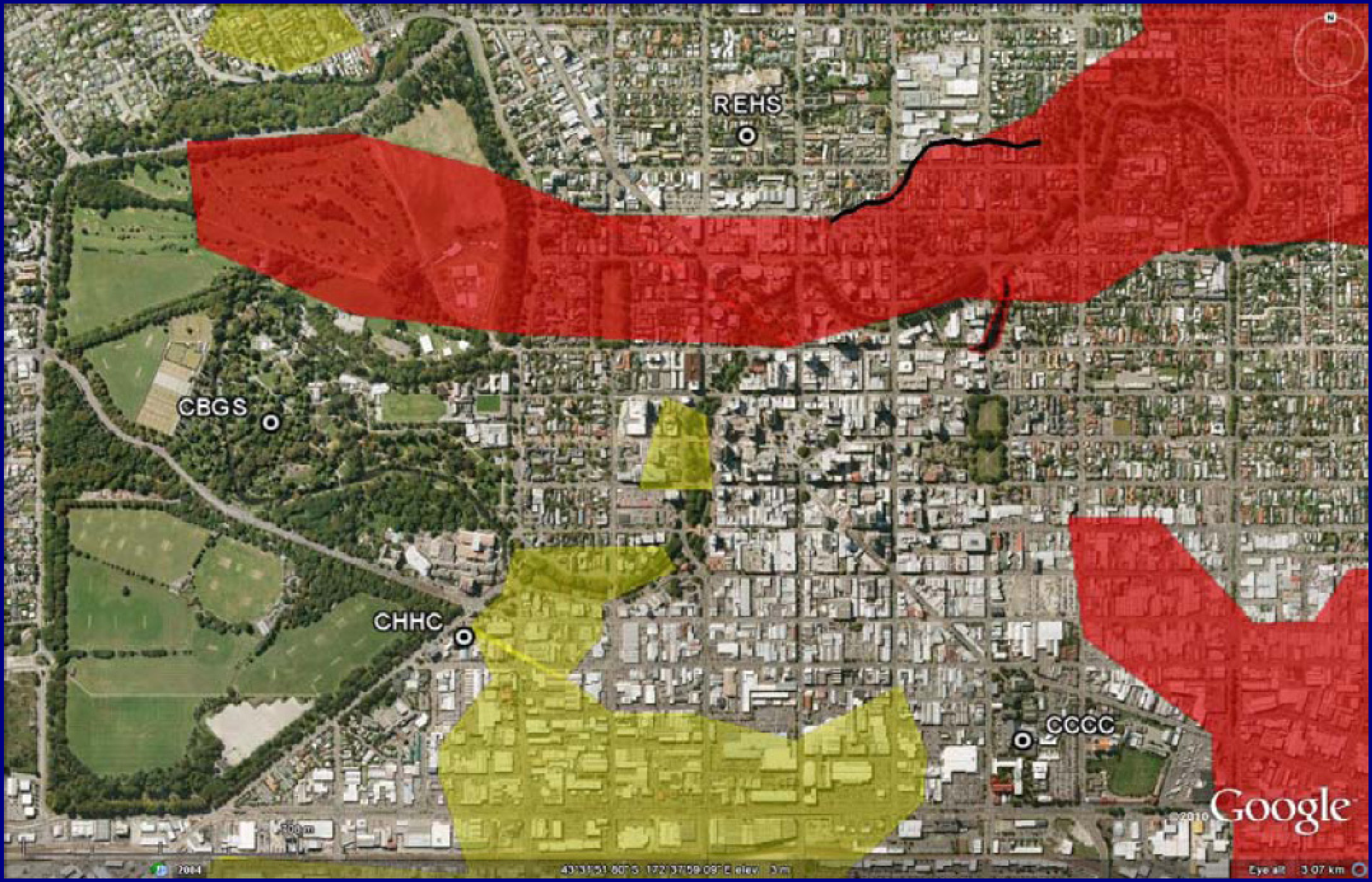
Typical Causes of *'Failure'* in the CBD

Typical Foundation Types

Foundation type	*Building type*	*Foundation soils*
Shallow foundations (Isolated spread footings with tie beams)	• Multi-storey buildings • Low-rise apartment buildings	• Shallow alluvial gravel • Shallow sands, silty sands
Shallow foundations (Raft foundations)	• Multi-storey buildings • Low-rise apartment buildings with basement	• Shallow alluvial gravel • Shallow sands, silty sands
Deep foundations (shallow piles)	• Low-rise apartment buildings	• Medium dense sands (Soft silts and peat at shallow depths)
Deep foundations (deep piles)	• Multi-storey buildings	• Medium dense to dense sands (Areas of deep soft soils or liquefiable sands underlain by dense sands)
Hybrid foundations (combined shallow and deep foundations or combined short and long piles)	• Multi-storey buildings	• Highly variable foundation soils including shallow gravels and deep silty or sandy soils beneath the footprint of the building

(Table 2)

CBD Liquefaction Map

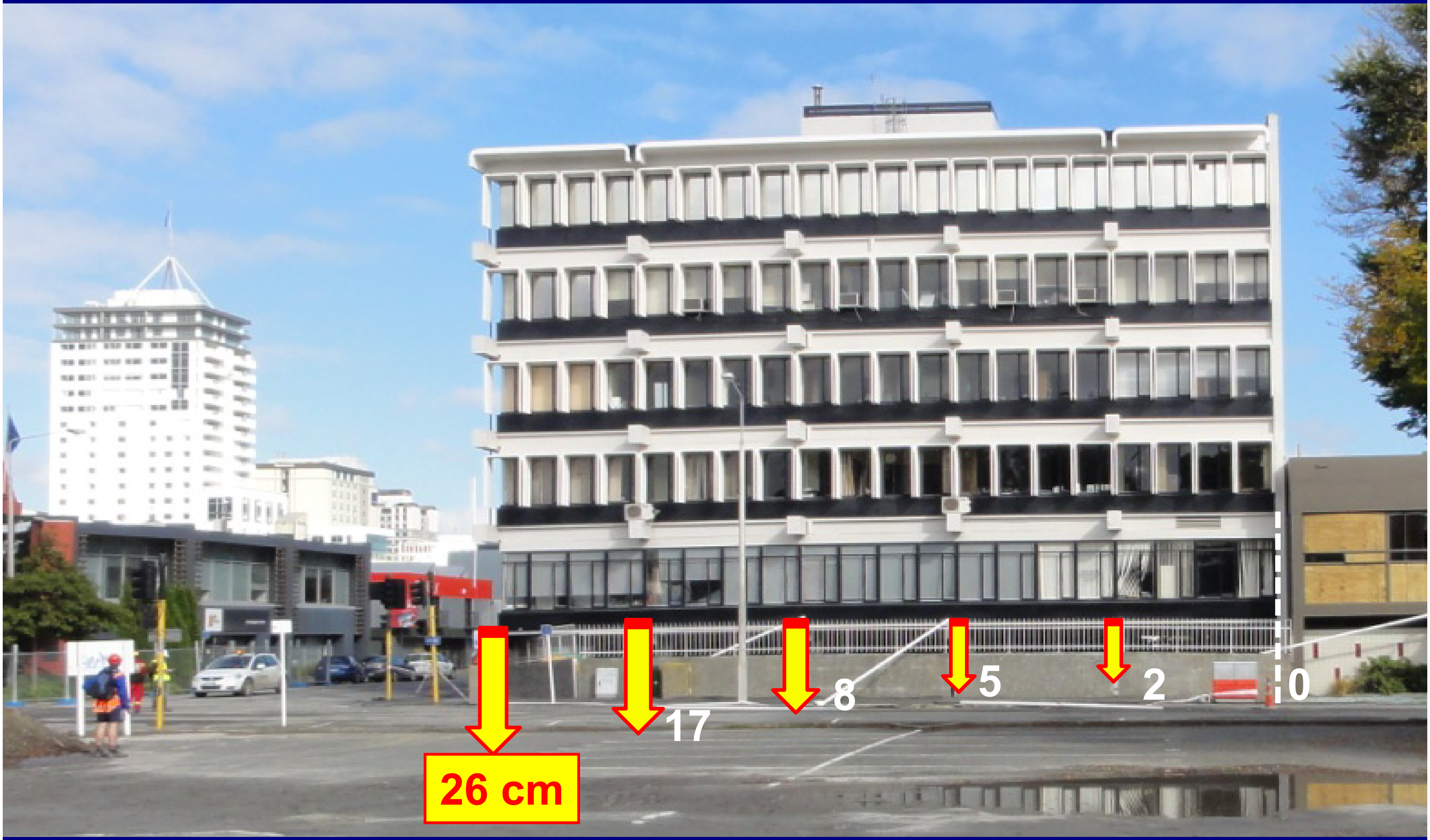


(Figure 10)

Drive through reconnaissance map (Cubrinovski and Taylor, 2011)

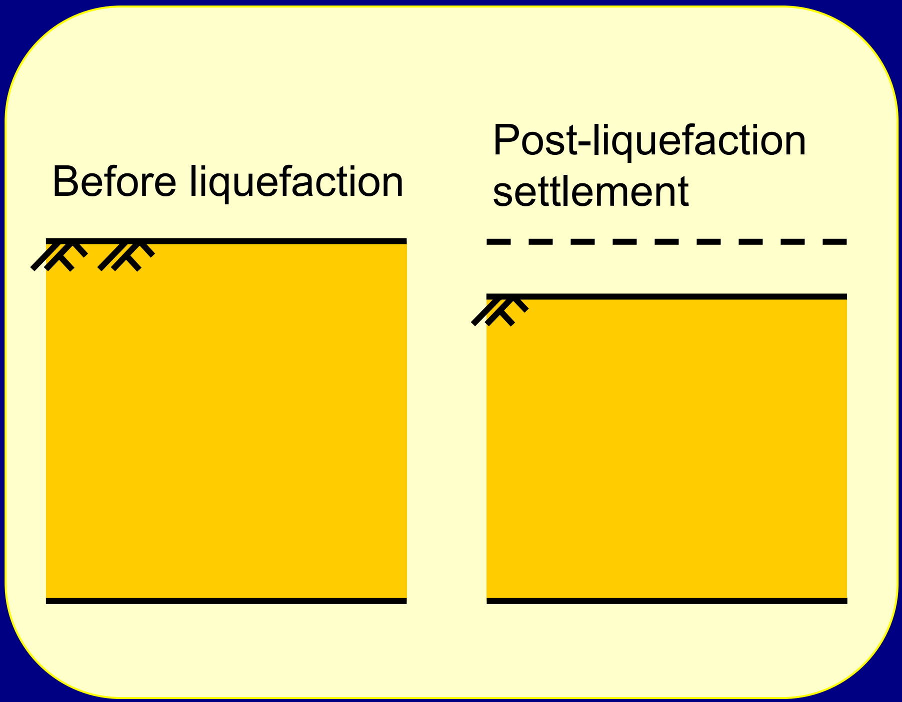
Differential Settlement, Tilt and Sliding

Differential Settlements



Punch-through Settlement (sinking)

In the free field



Building settlement