CPT-based Simplified and Advanced Liquefaction Assessment of CentrePort Gravels

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DT1: Integrated Seismic Geohazards
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Overview

Wellington Port Background

Observed Damage in Recent Earthquakes

Cone Penetration Test Interpretation

Simplified Liquefaction Assessment

Effective Stress Analysis

Concluding Remarks

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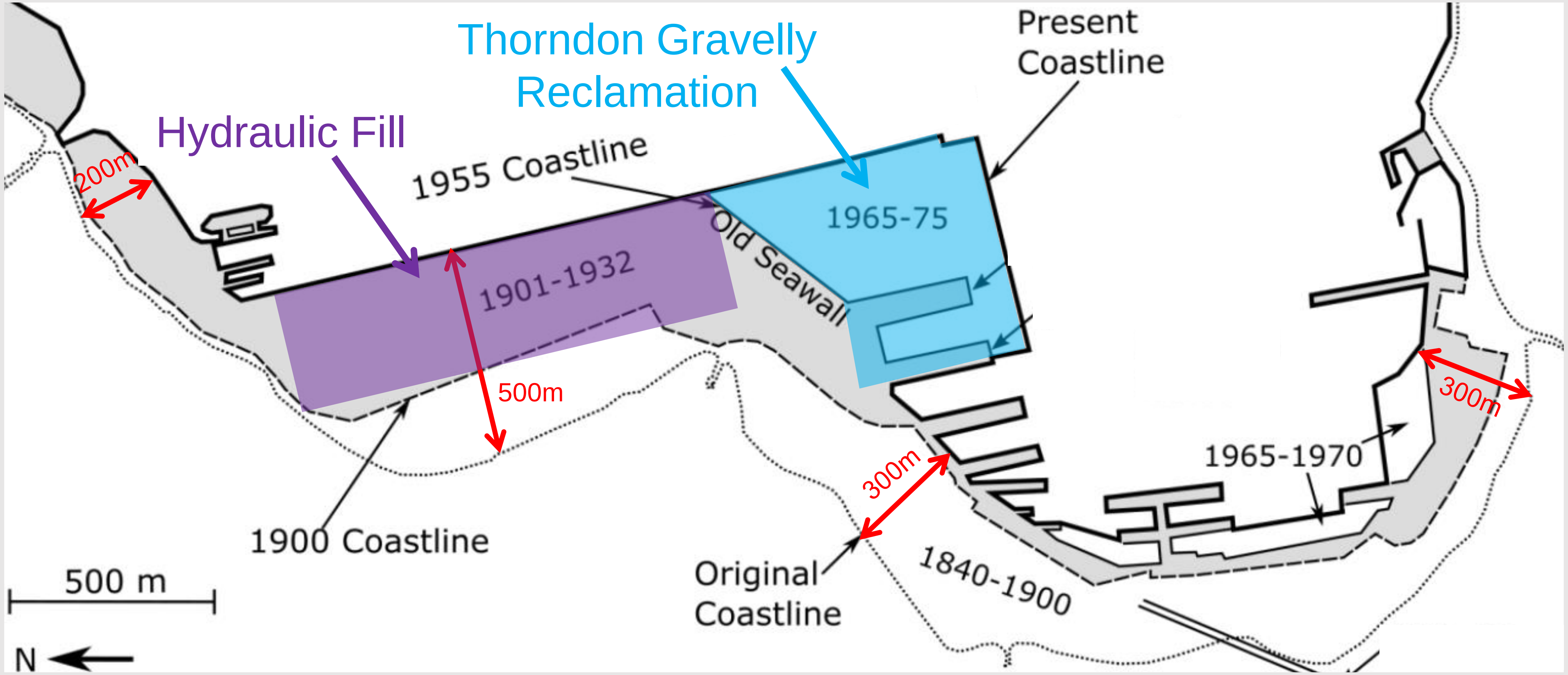
Port on Reclaimed Land

Port Reclamation History



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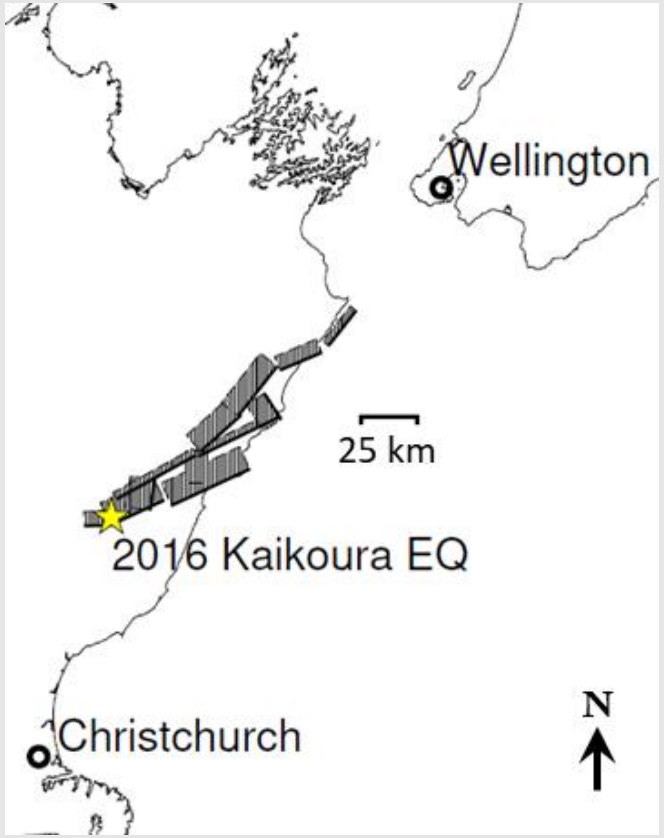
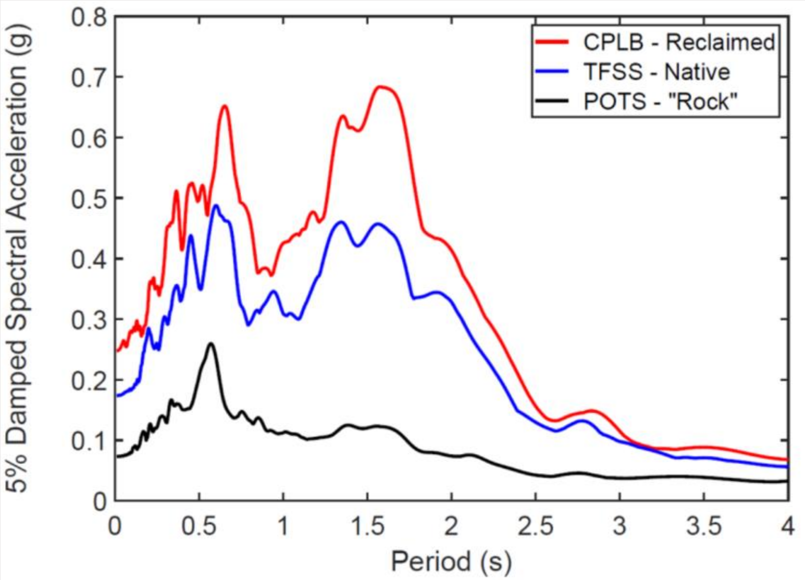
2016 Kaikoura Earthquake (M_w7.8)





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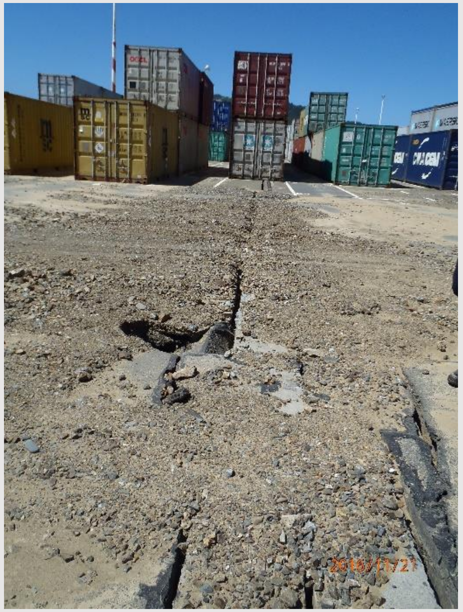
2016 Kaikoura Earthquake (M_w7.8) Damage

Thick ejecta
(up to 200 mm)



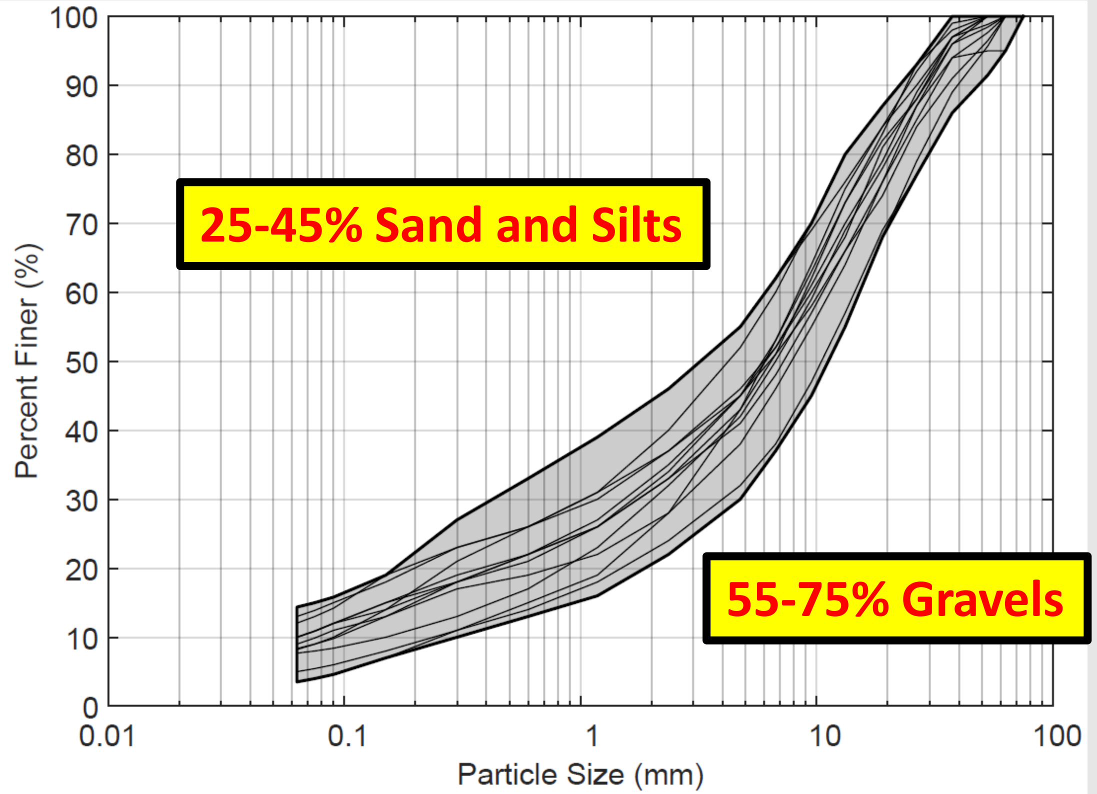
Settlement of fill
(up to 500 mm)

Damage to Thorndon and King's wharf piles and deck
(severe)

Major damage

Cubrinovski et al. (2017) NZSEE Bulletin

Gravelly Ejecta



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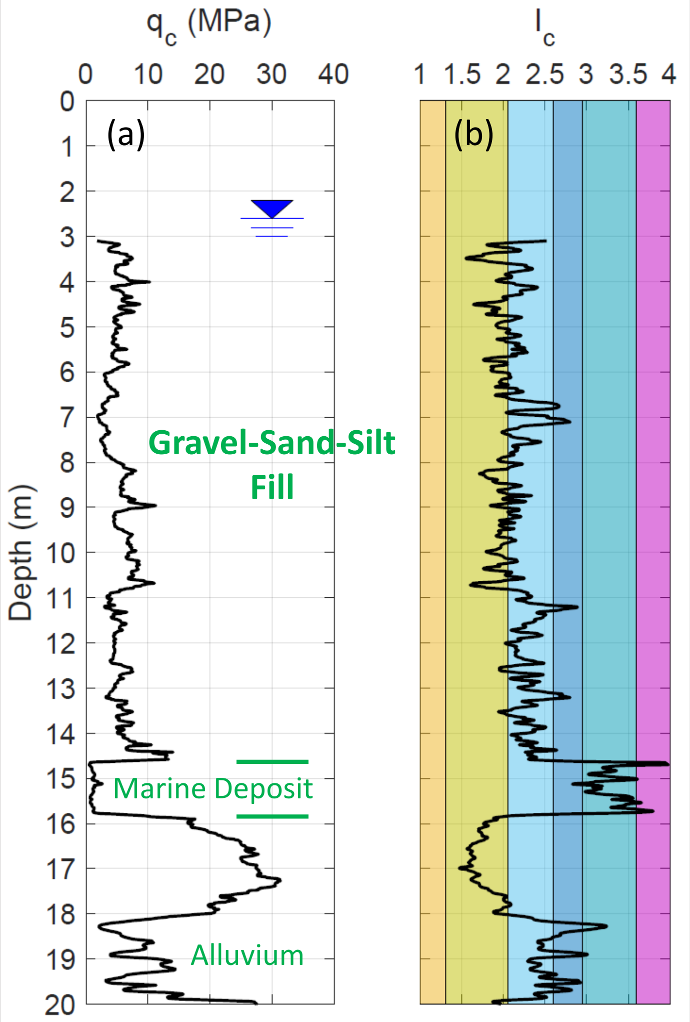
Site Characterization



- Sand-silt controlled matrix
- Indicates performance during Kaikoura EQ

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Simplified Method: Applicability?

- Simplified liquefaction methods: Based on observations and largely empirical

- Liquefaction case histories are dominated by sands and sands with fines

	SPT-Based Database *(Boulanger and Idriss 2014)*	V_s-Based Database *(Kayen et al. 2013)*	CPT-Based Database *(Boulanger and Idriss 2014)*
Total	~250	~415	~250
Gravels	< 20%	< 15%	< 5%

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Key Assumptions in the Procedure

Three key steps in liquefaction assessment (*CRR* and settlement)

1. Measure q_c throughout depth
   - High-quality CPTs challenging due to presence of large particles

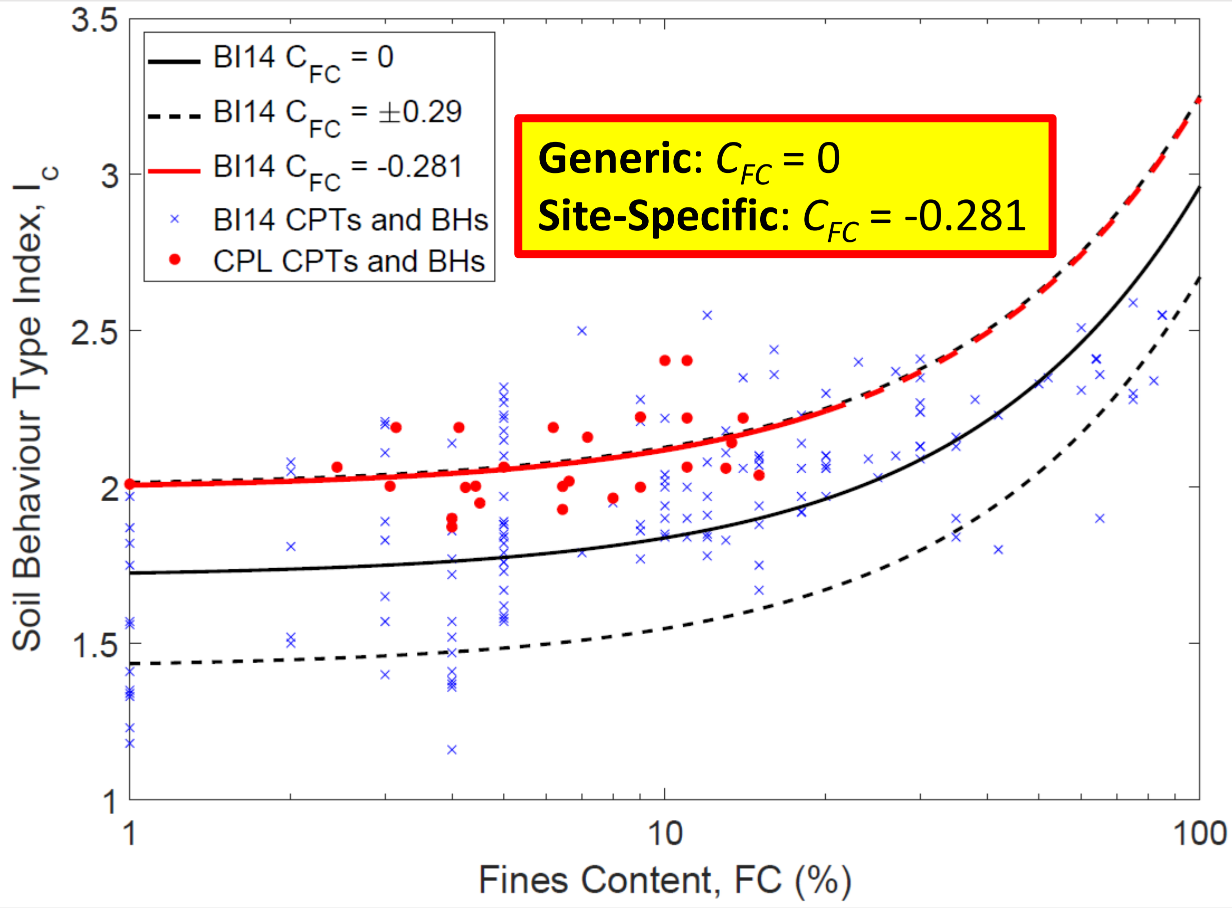
2. Correct q_c to clean-sand equivalent cone tip resistance, q_{c1Ncs}
   - Via a single 'material parameter' (*FC* or I_c)
   - Derived empirically from liquefaction case histories of sands (with fines)

3. Correlate q_{c1Ncs} to *CRR* and associated settlement
   - Implicit use of relative density (D_R; e.g. Ishihara and Yoshimine 1992)
   - D_R – q_{c1Ncs} OK for clean sands, but serious issues for gravels

Material Characterization

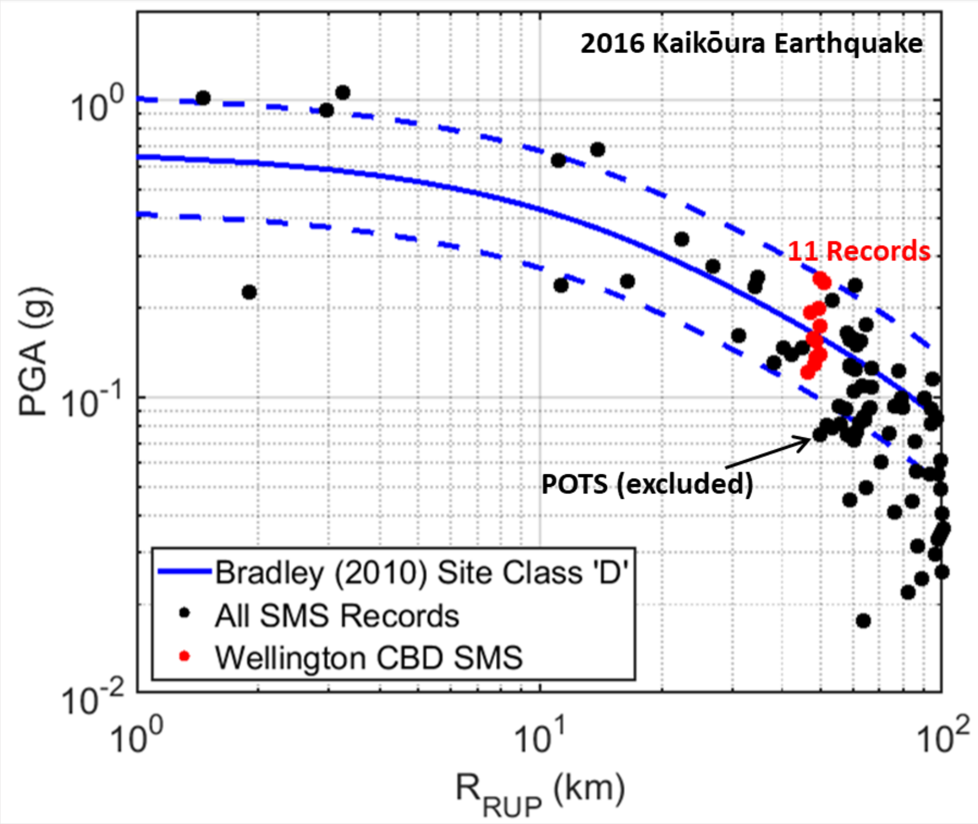
Methods:

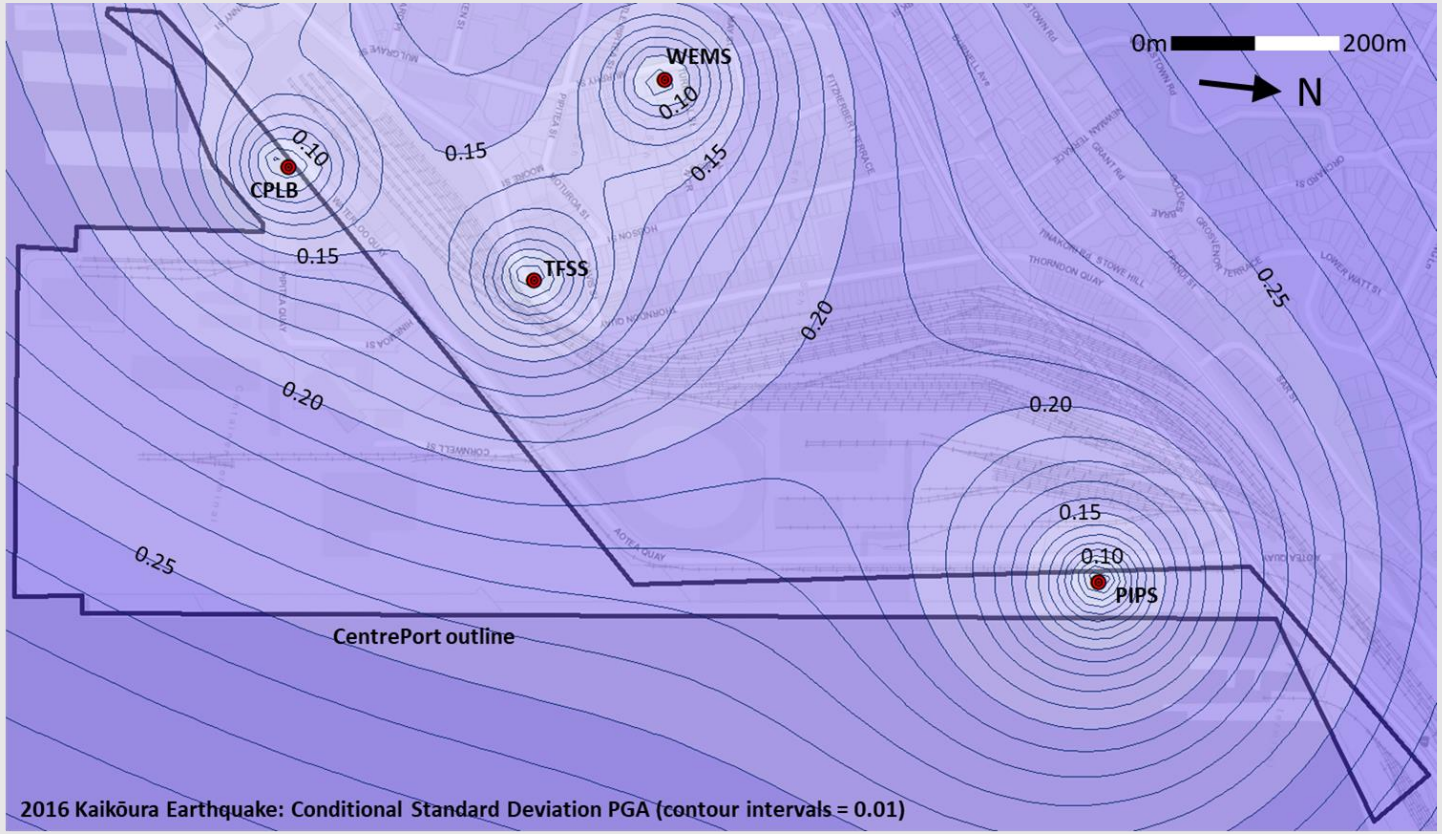
1. Robertson and Wride (1998; RW98) – I_c
2. Boulanger and Idriss (2014; BI14) – *FC* or I_c
   a) User-defined *FC* value
   b) Estimate *FC* using generic *FC* – I_c correlation (sand case histories)
   c) Estimate *FC* using site-specific *FC* – I_c correlation



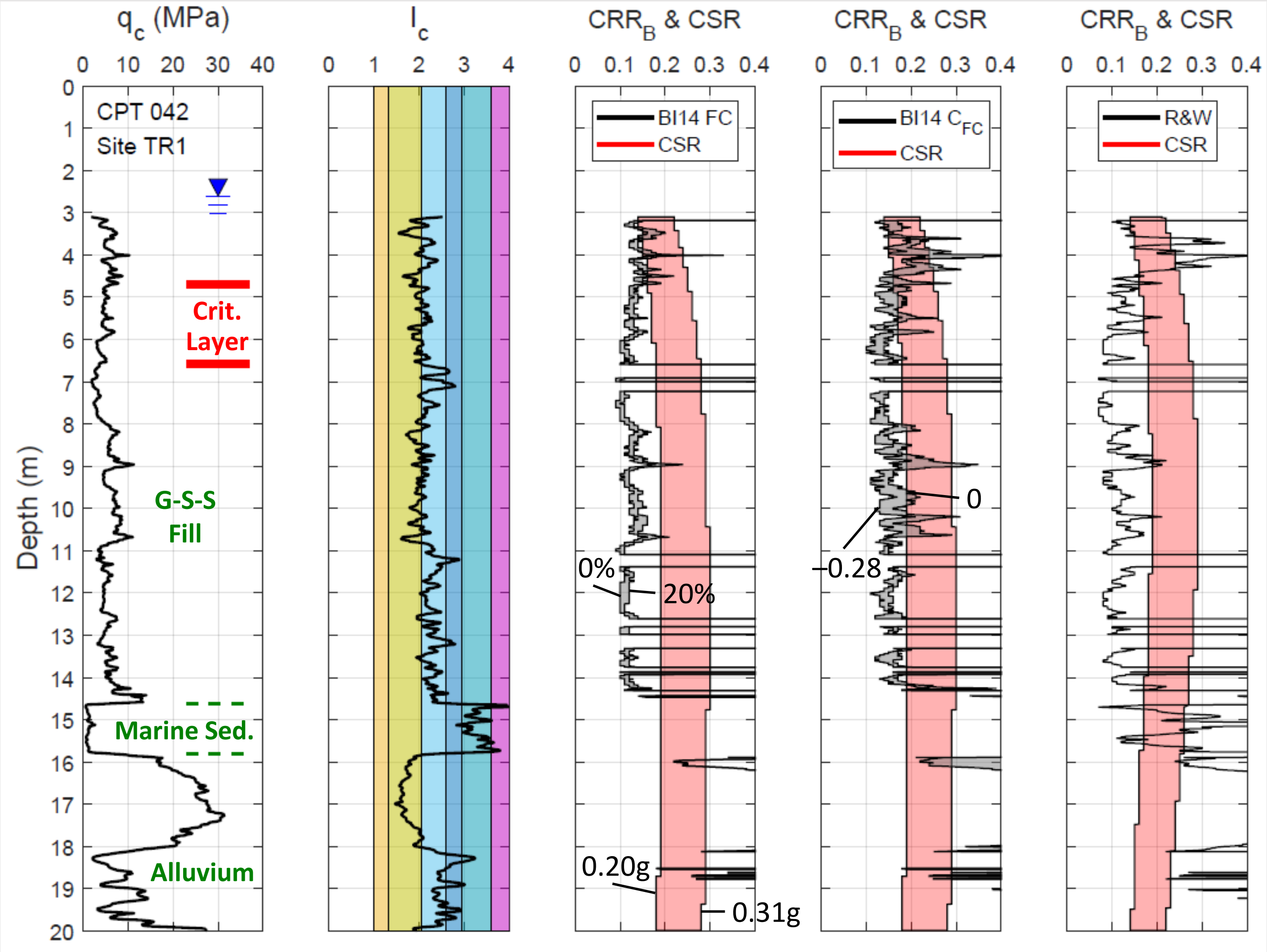
Uncertainty in the Demand

Condition PGA uncertainty estimates:





Simplified Assessment: Triggering



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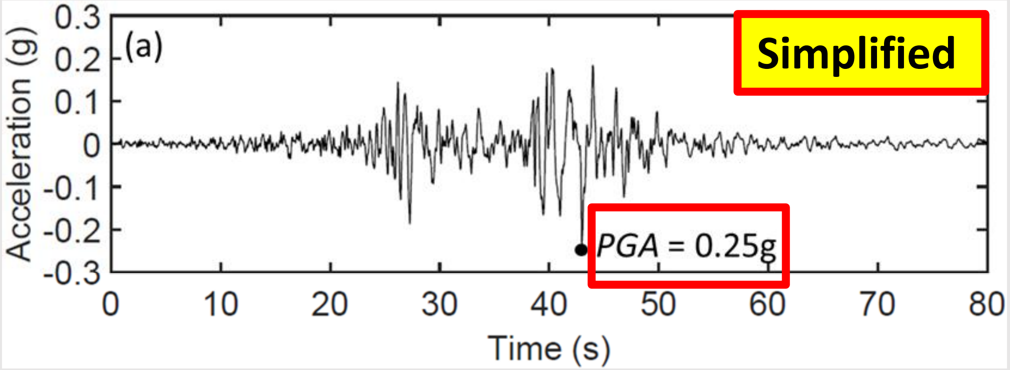
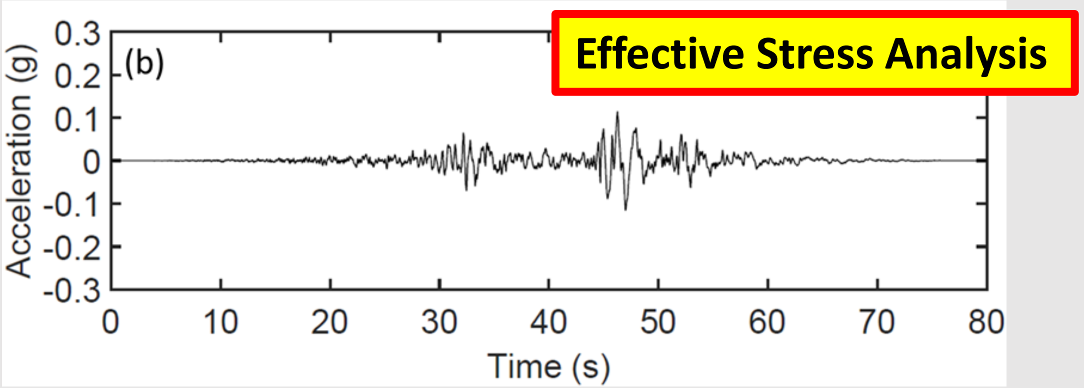
Effective Stress Analysis

- Dynamic (**time history**) analysis





- Finite element/difference model with a two-phase medium (**solid** and **fluid** phase) formulation: accounts for excess pore water pressures
- Sophisticated constitutive model: a set of equations describing **stress-strain material response**

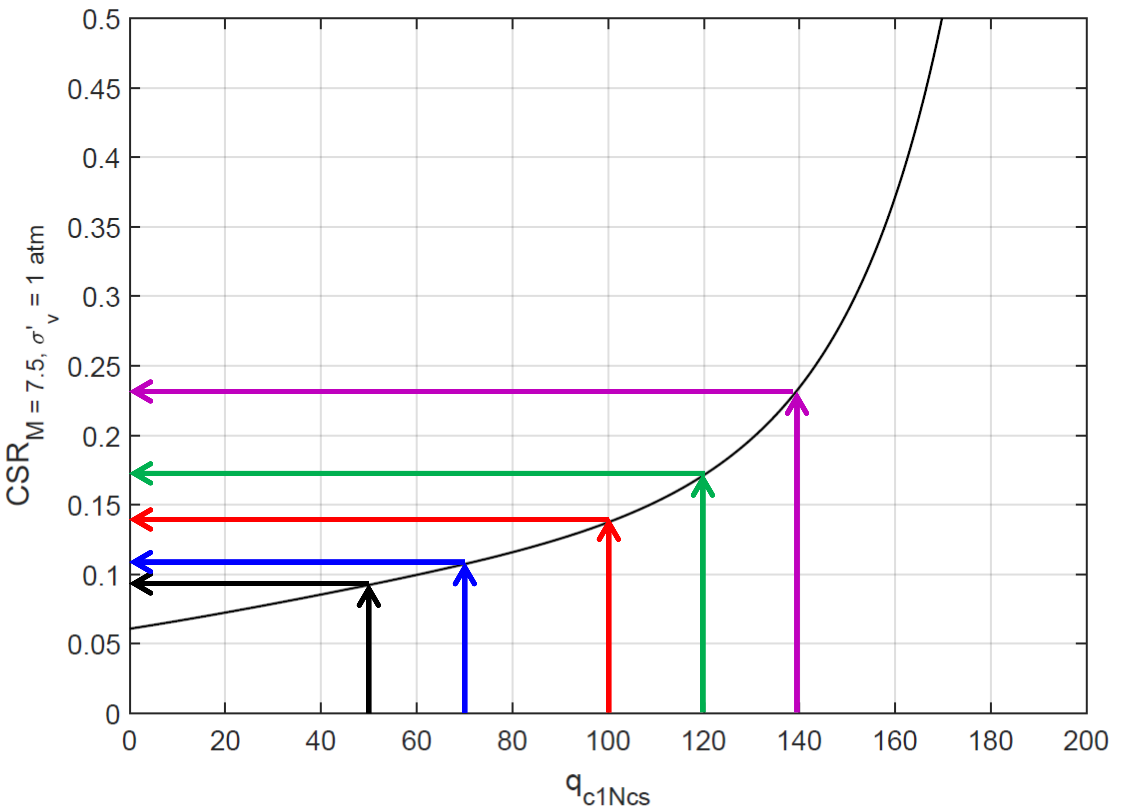
Stress-Density Constitutive Model

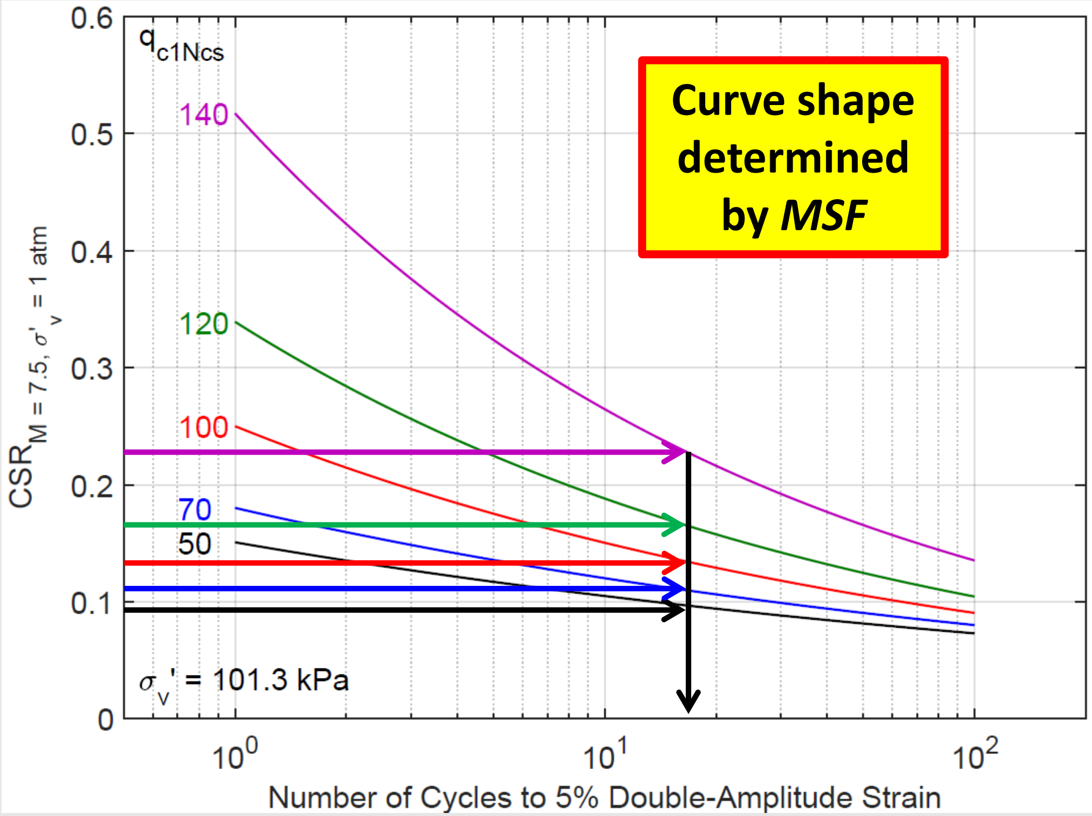
Key features:

1. Stress-strain relationship
2. Elastic-plastic formulation (incremental formulation)
3. Uses the state-concept interpretation (can be modelled over several densities)
4. Soil behaviour is determined by several material parameters which can be determined in two ways
   a) Rigorous field and laboratory tests
   b) **Empirical relationships (e.g. Boulanger and Idriss 2014)**

Stress-Density Constitutive Model

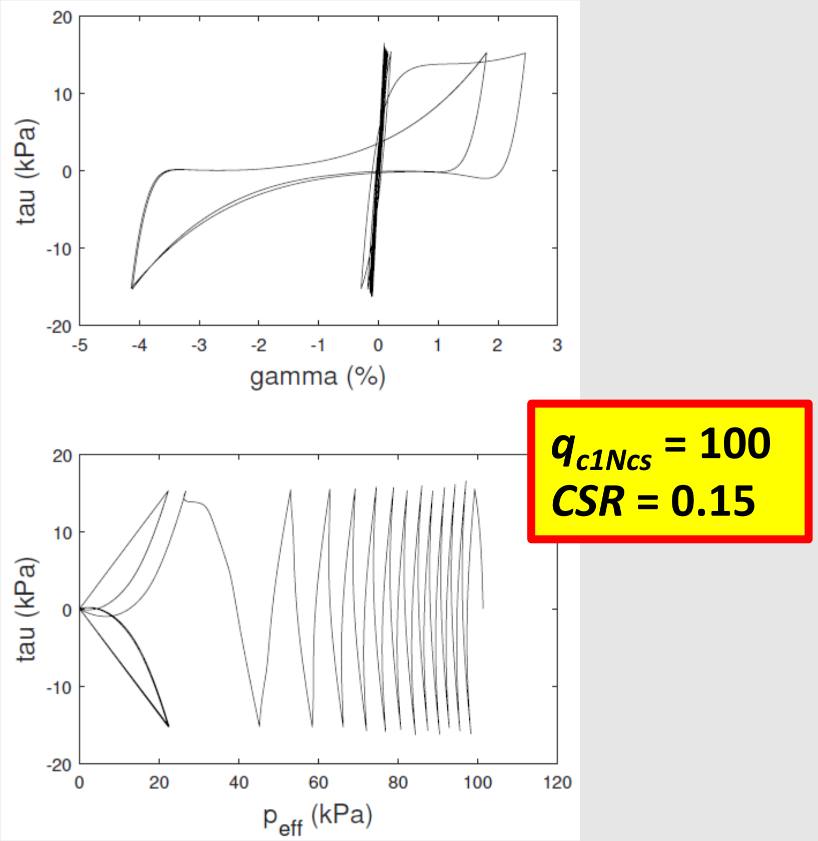
Boulanger and Idriss (2014) empirical relationship:

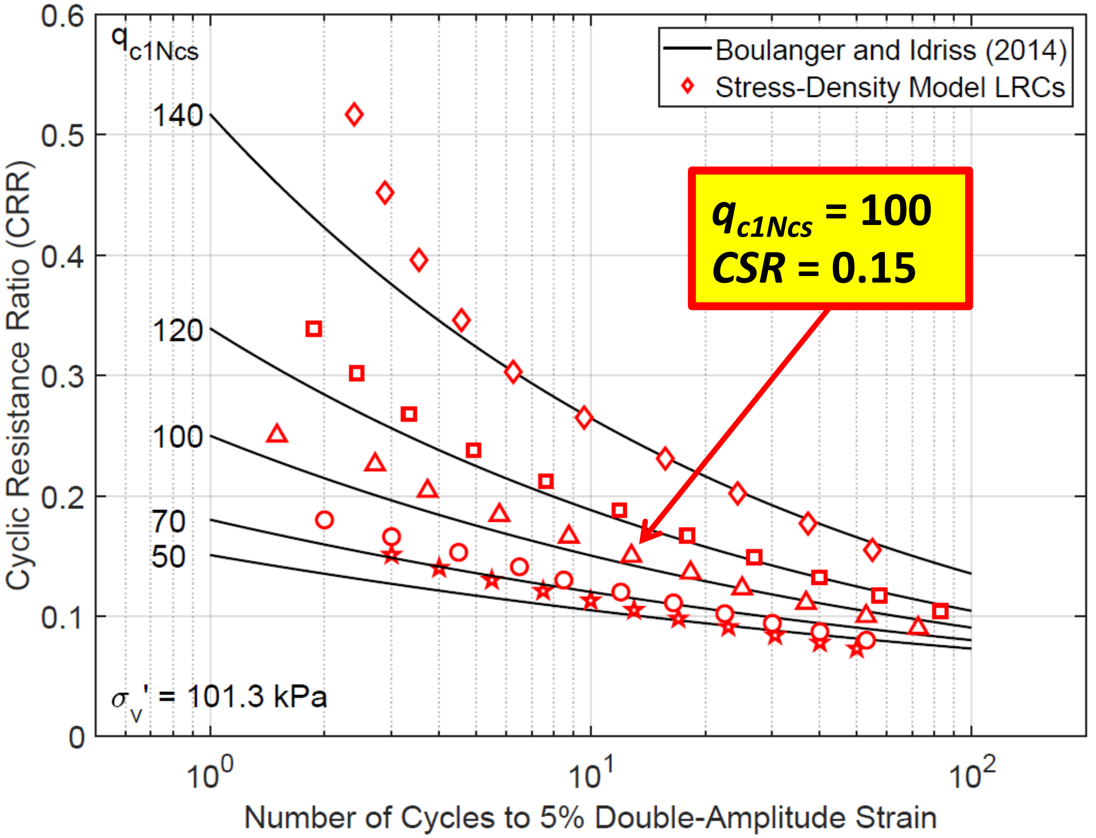




Stress-Density Constitutive Model

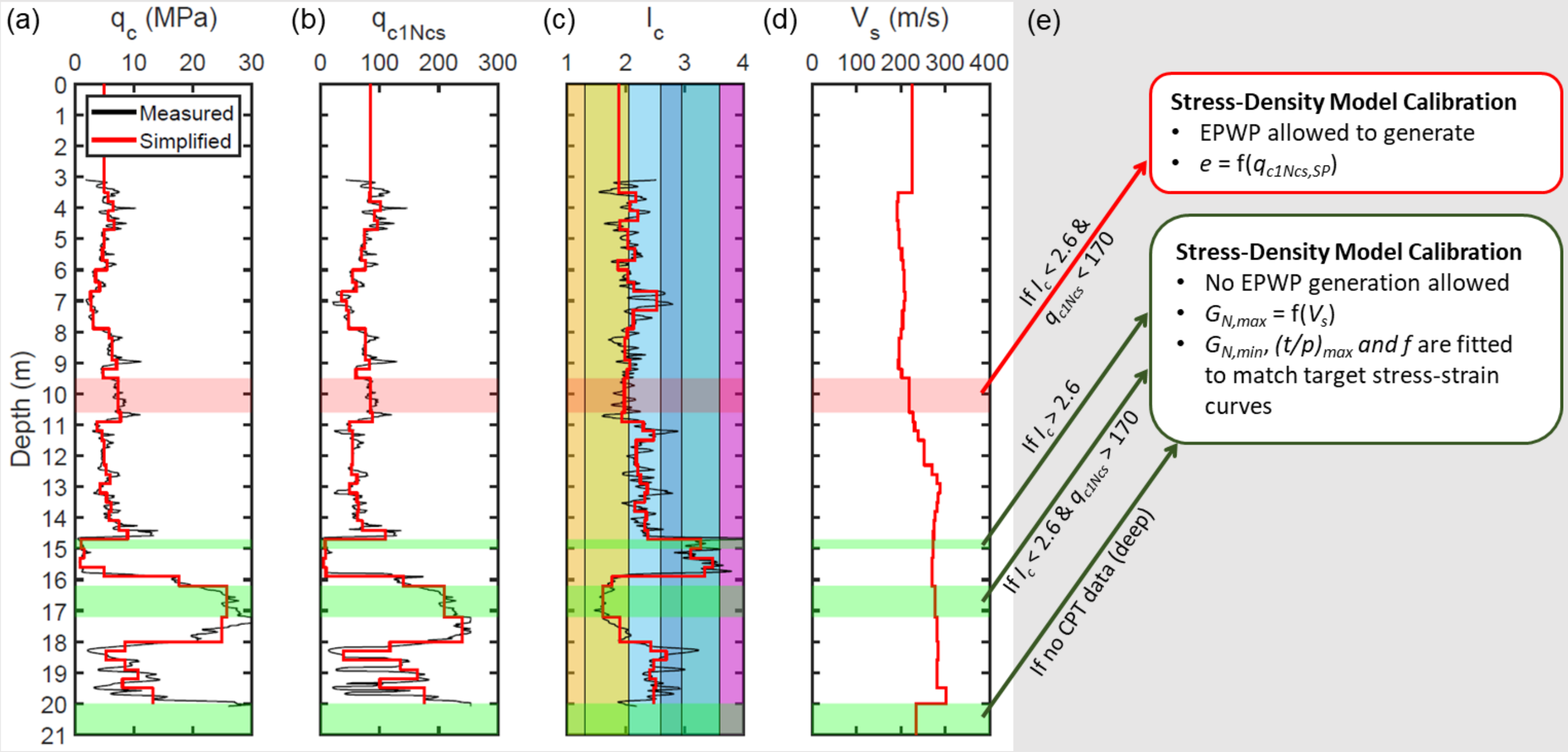
Boulanger and Idriss (2014) empirical relationship:



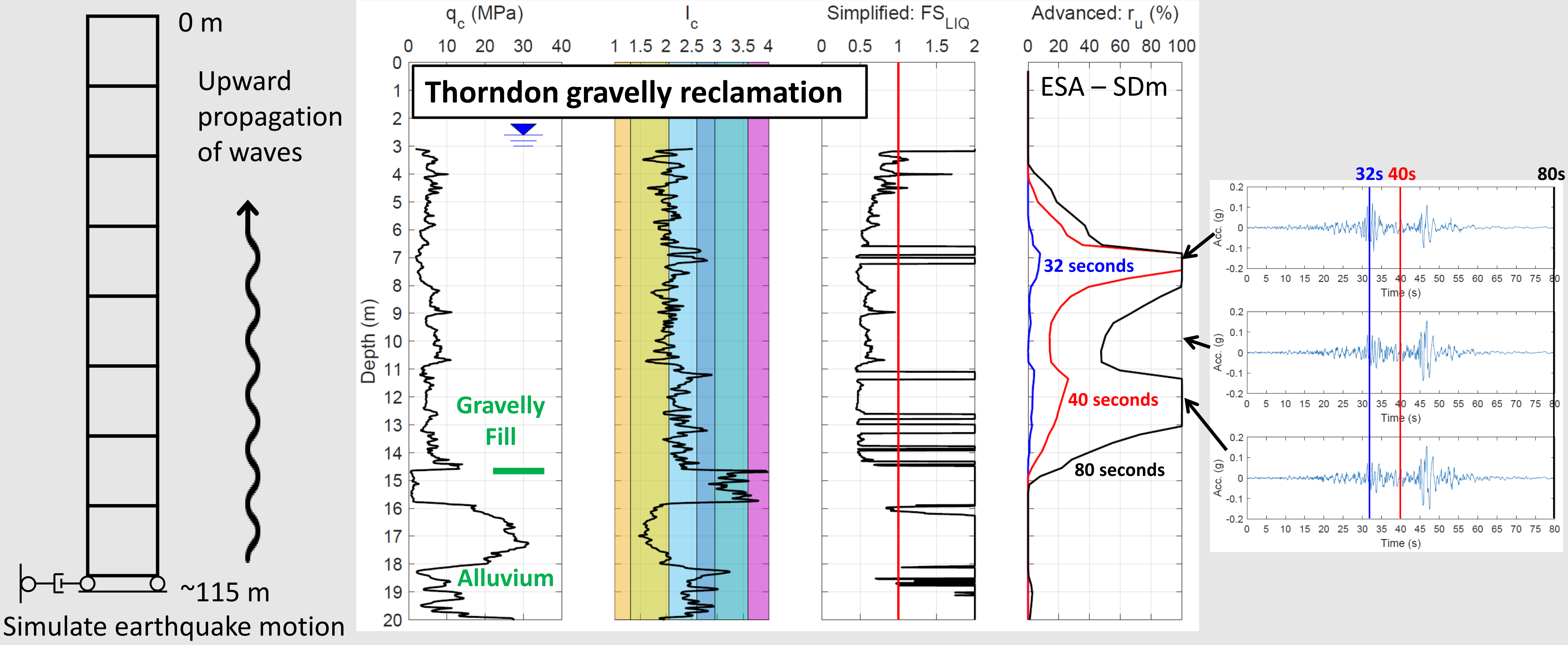


CPT-Based Analysis

Use of CPT for effective stress analysis



Analysis Results



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- Port reclamation: complex and rich
- Case history improves understanding of gravel liquefaction using both simplified and advanced methods
- Outputs:
  - Insights in applicability of existing assessment methods for NZ-specific case histories
  - Development of simplified, advanced and laboratory assessment methods for nonstandard soils
  - Liquefaction hazard maps at and around the waterfront
  - Journal publications (Cubrinovski et al. 2017; 2018; Dhakal et al. 2020a; 2020b; 2021; Several more to come)

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Thank You for Your Attention

Any Questions?

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