Seismic liquefaction assessment of unconsolidated soils using various field methods

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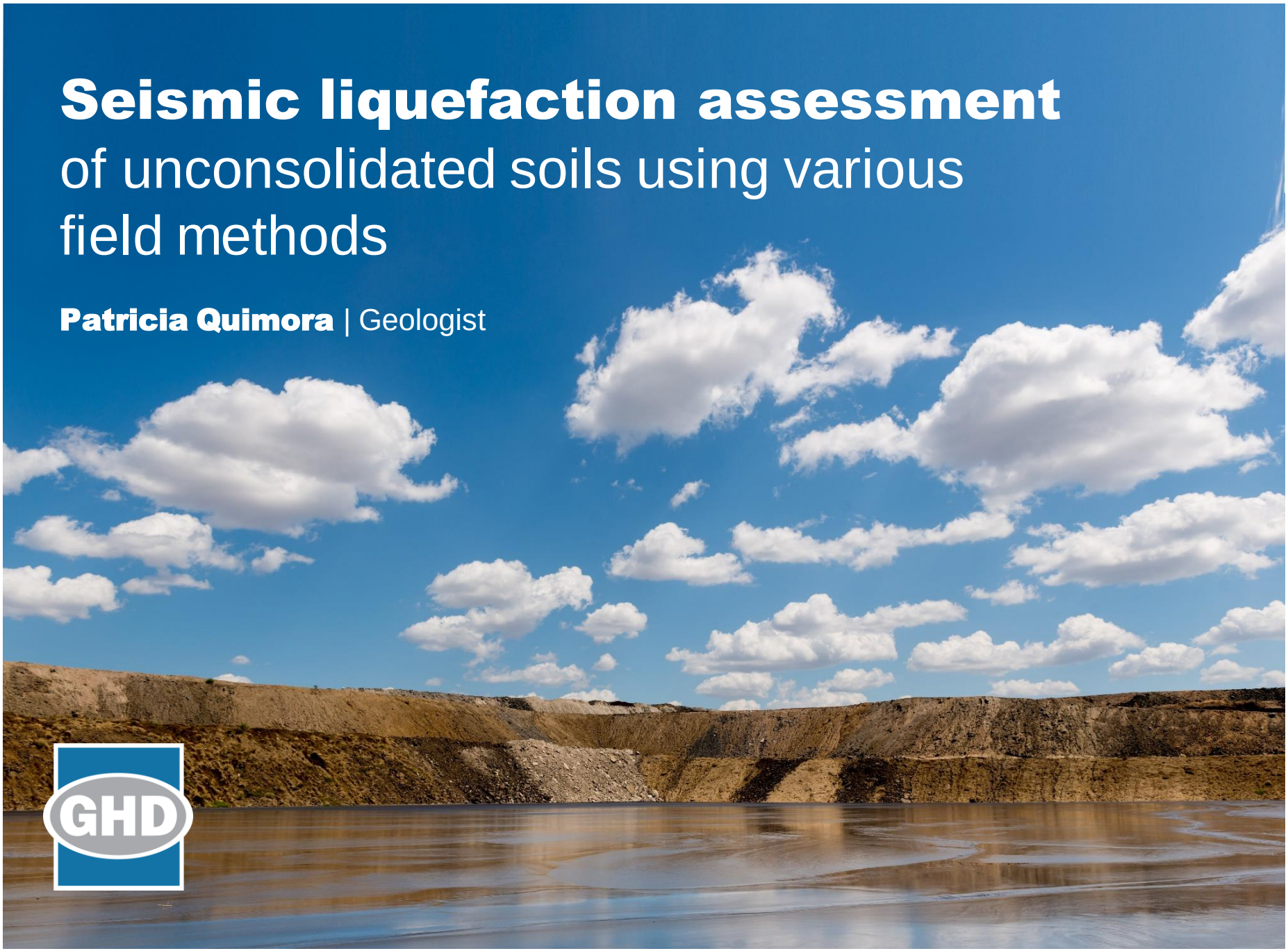


Outline

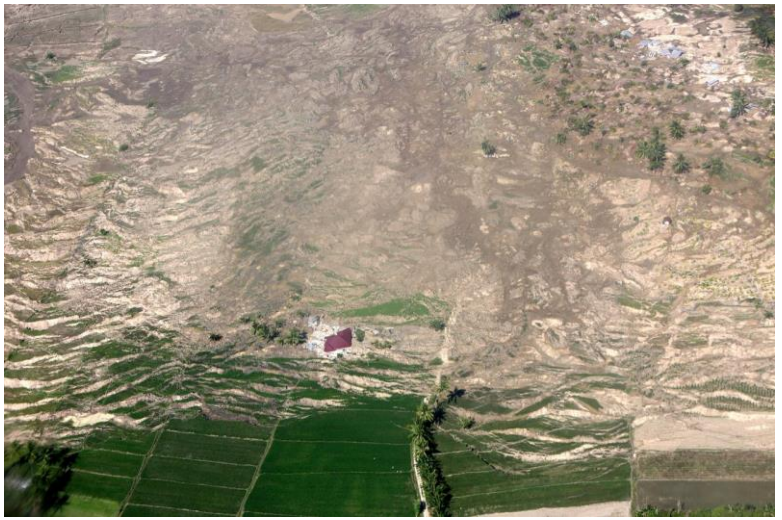
- Overview
- In-situ methods for liquefaction screening
  - Borehole drilling, SPT and identification tests
  - CPT
  - Shear wave velocity (Vs) profiling
- Case study with preliminary liquefaction assessment
- Summary and recommendations

Overview – What is liquefaction?

Liquefaction is a phenomenon where saturated, loose soil is subjected to a dynamic load which results to loss of shear strength (Coduto, 1999).

This initiates flow movement which results in lateral spreading and large settlements.

Underground utilities rising to the surface in Dagupan due to the 1990 Luzon earthquake
https://www.phivolcs.dost.gov.ph/index.php/earthquake/earthquake-hazards



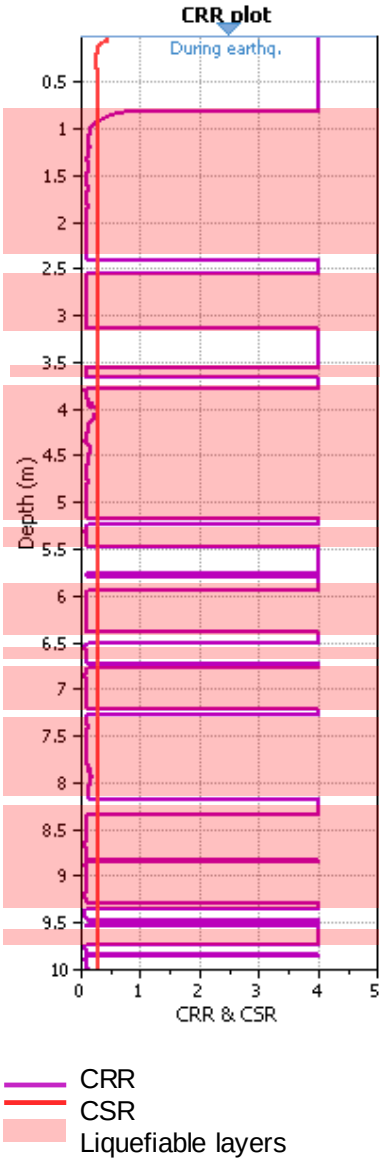
Liquefaction in Palu, Central Sulawesi, Indonesia
Reuters, 2018

Overview – Liquefaction susceptibility

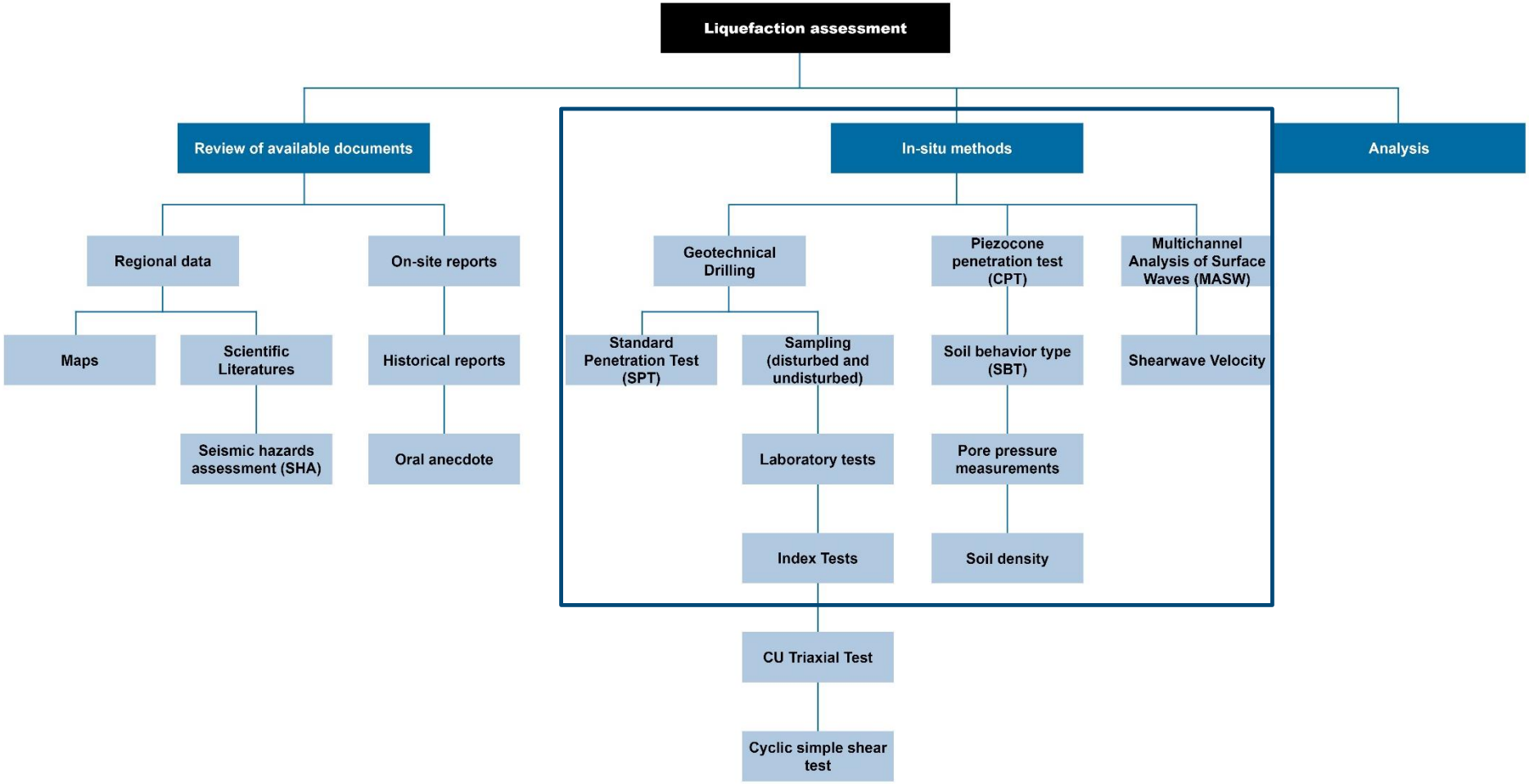
Liquefaction occurs when the **Cyclic Stress Ratio (CSR)** or the seismic demand placed on a soil layer, exceeds the **Cyclic Resistance Ratio (CRR)** or the capacity of the soil to resist liquefaction.

Criteria for liquefaction susceptibility

- Contractive soil (cohesionless, loose material such as silts and sands)
- Shallow groundwater, high moisture content
- Cyclic motion usually produced by earthquakes



Methodology – Preliminary liquefaction assessment

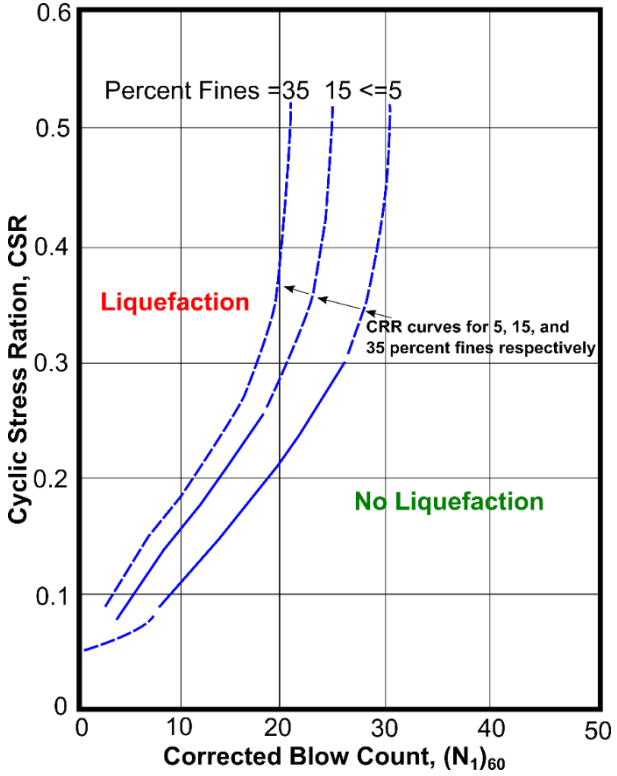


Borehole drilling - Standard Penetration Test (SPT)

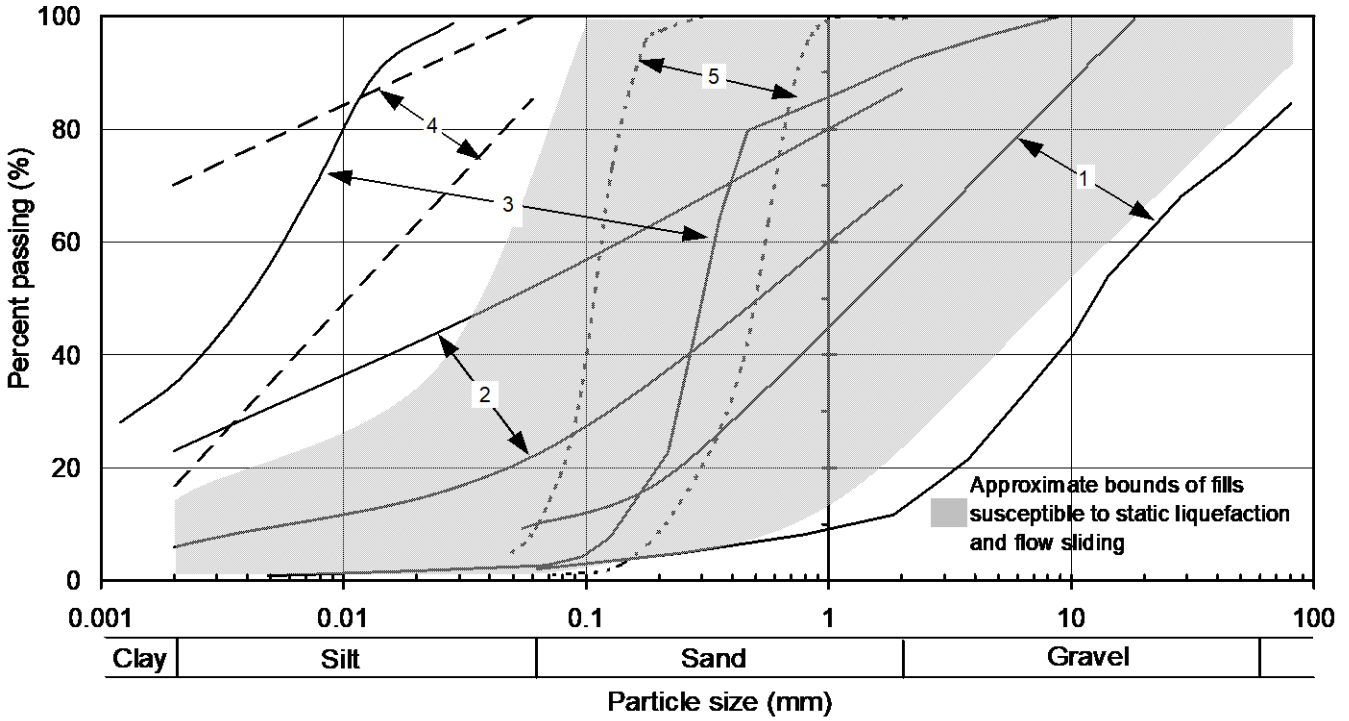
Geotechnical drill rig

Soil samples from drilling

SPT sample showing dense material at 32 m



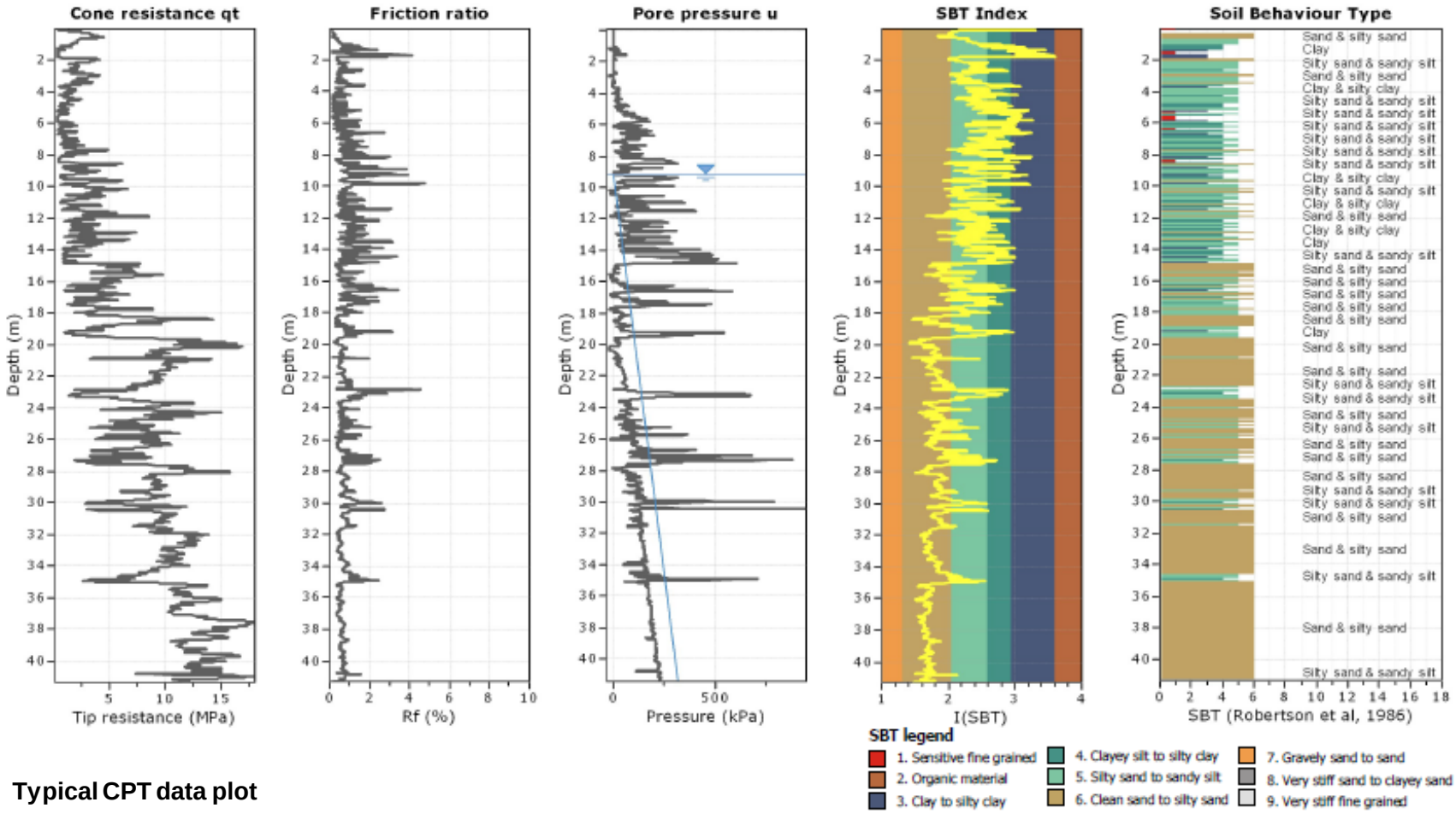
Borehole drilling – Soil classification tests



1 - Coarse grained coal mine waste (Dawson et al 1998; Taylor 1984; Bishop et al 1969; Hutchinson 1986)
2 - Loose silty sand fills, Hong Kong (upper and lower quartile of pre 1977 fills (HKIE 1998))
3 - Hydraulically placed mine tailings and fills in dam embankments (various published sources)
4 - Sensitive clays (indicative limits from: Lefebvre 1996; Bentley & Smalley 1984; Mitchell & Markell 1974; Hutchinson 1961, 1965)
5 - Sub-aqueous slopes, natural and fill slopes (Koppejan et al 1948; Kramer 1988; Sladen & Hewitt 1989; Cornforth et al 1974)

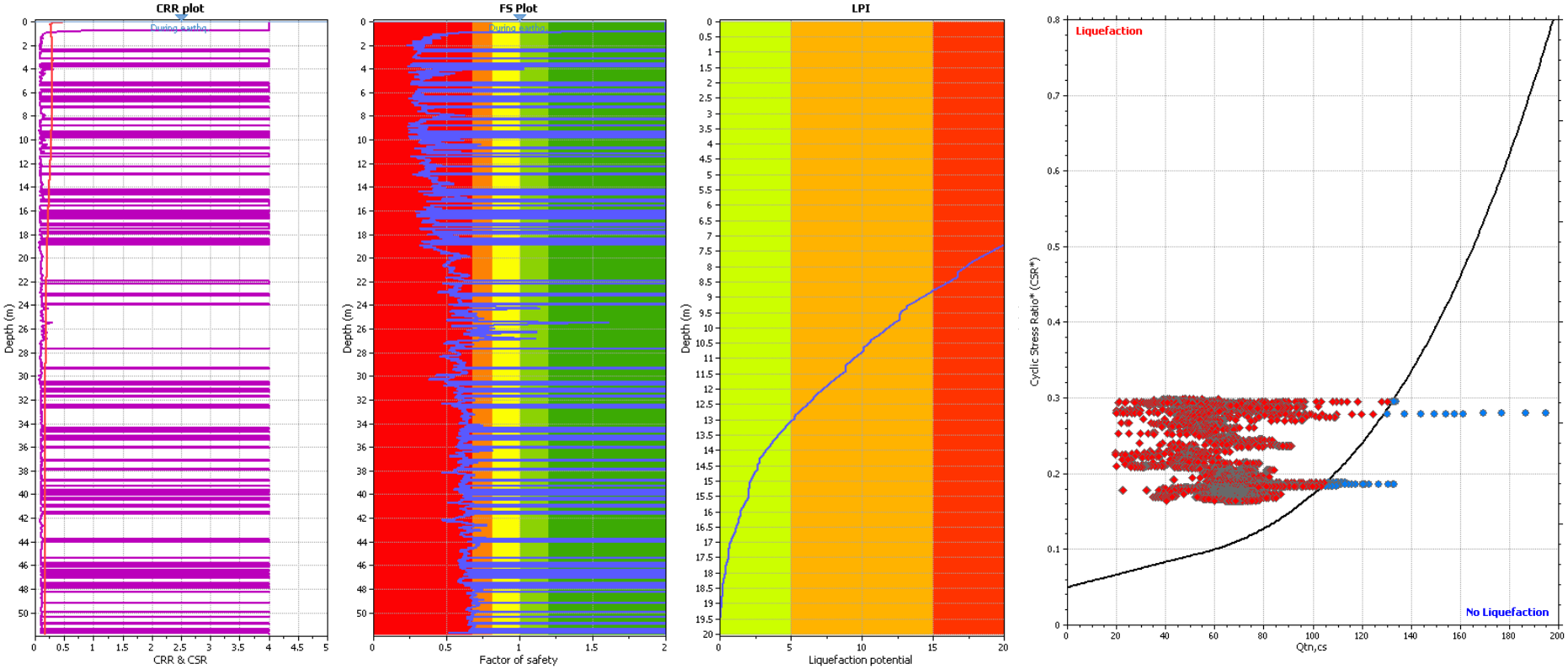
Particle size distribution (Hunter and Fell, 2003)

Piezocone Penetration Test (CPTu)



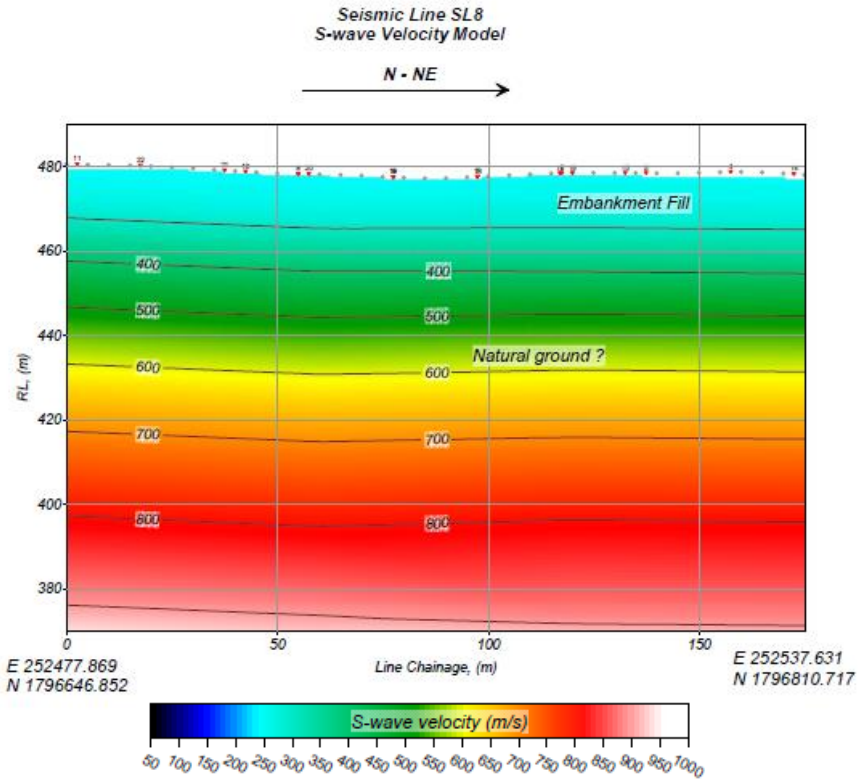
Typical CPT data plot

Piezocone Penetration Test (CPTu)

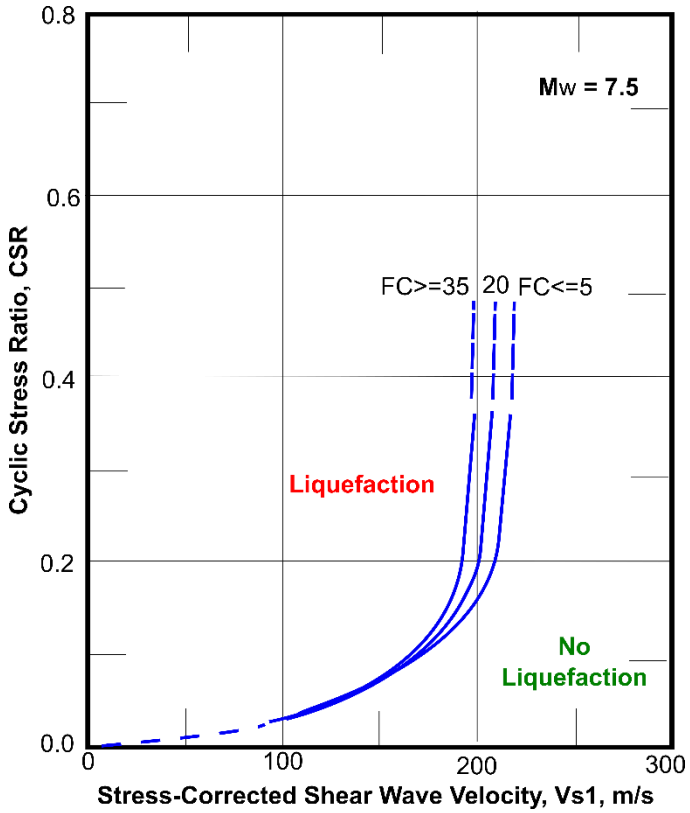


Sample cyclic liquefaction plots from CLiq

Shear wave velocity profiling– Multichannel Analysis of Surface Waves (MASW)



Typical shear wave velocity (Vs) model



Summary - Comparison between methods

Test type	Advantages	Disadvantages
Borehole drilling and SPT	Test provides soil samples for laboratory analyses	Quality control may vary from poor to good
CPT	Repeatability Provides a continuous profile for stratigraphic interpretation Seismic CPT can be conducted for in-situ Vs measurement	No soil samples can be collected to confirm estimated soil behavior type (SBT) Not recommended on gravelly layers and competent material
Vs profiling	Vs measurement can be done with various field methods Testing possible in gravelly, competent material	Vs measurements are made at smalls strains, while liquefaction is a large strain event No soil samples to confirm material classification

Case study– Investigation plan

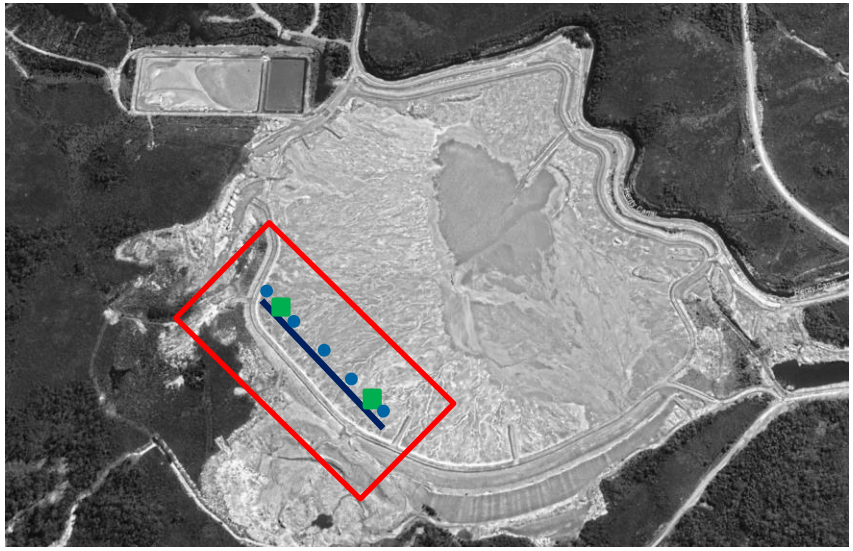
Project site: reclaimed site, tailings storage facility

Expected material:
- Recent manmade fill (silts and sands, boulders along embankment)
- Bedrock

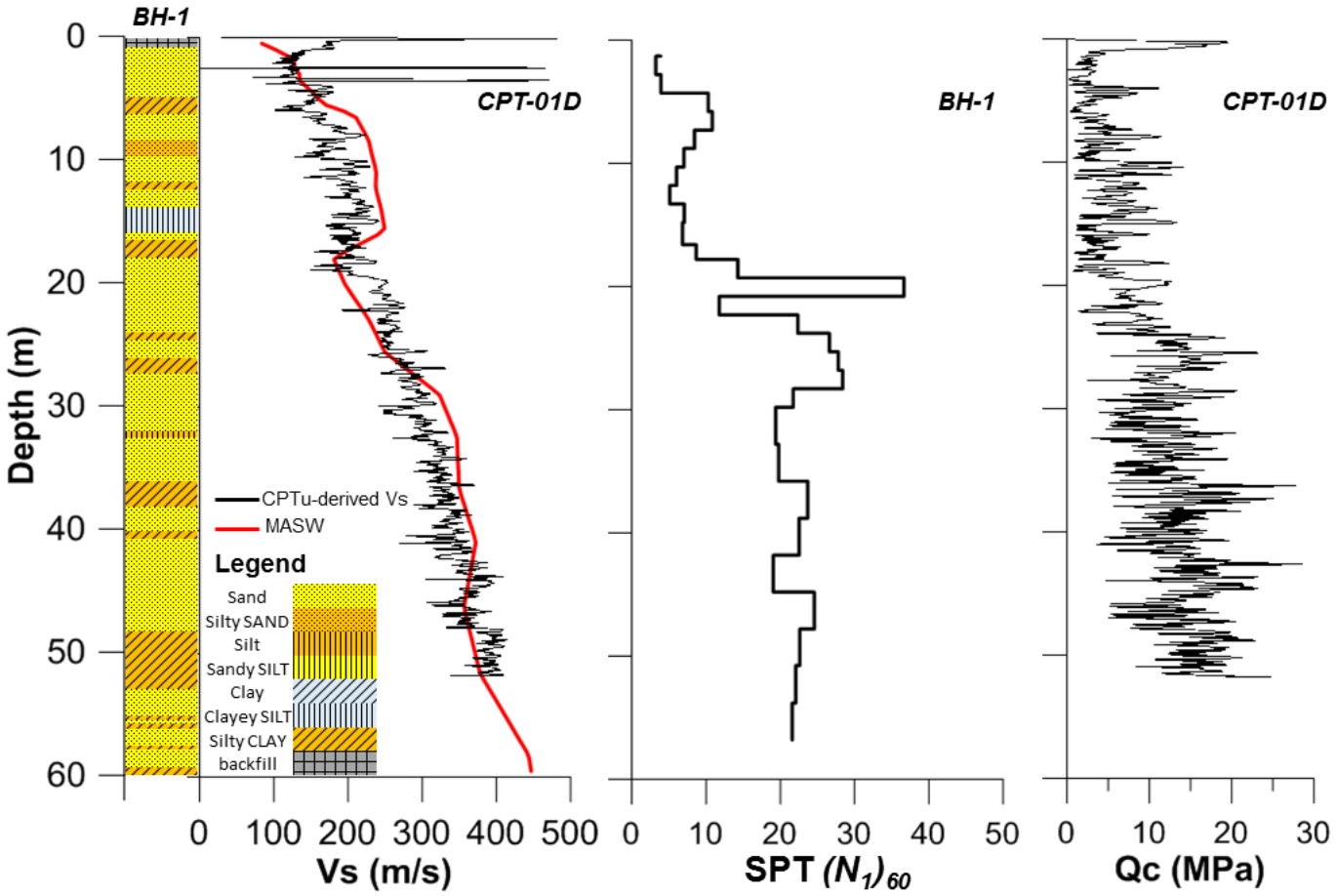
Groundwater level: 0 mbgl to 1 mbgl

Computed Mw: 7.5

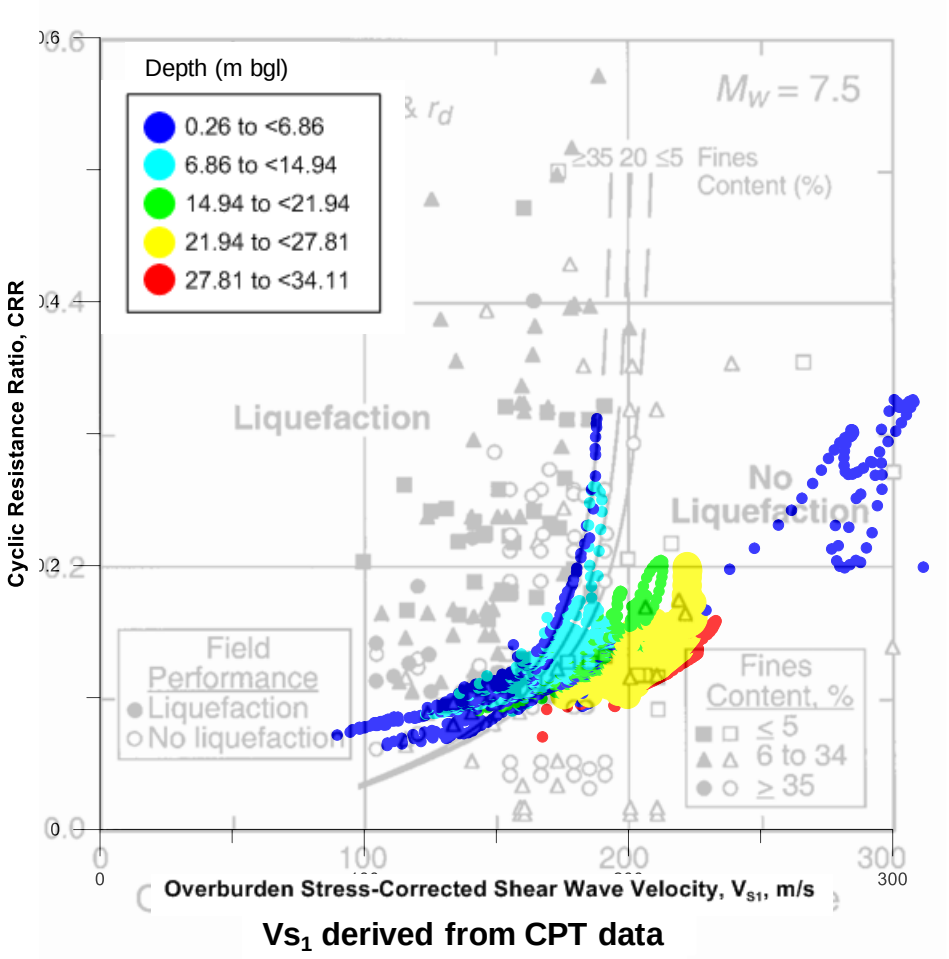
Computed Peak Ground Acceleration (PGA): 0.31

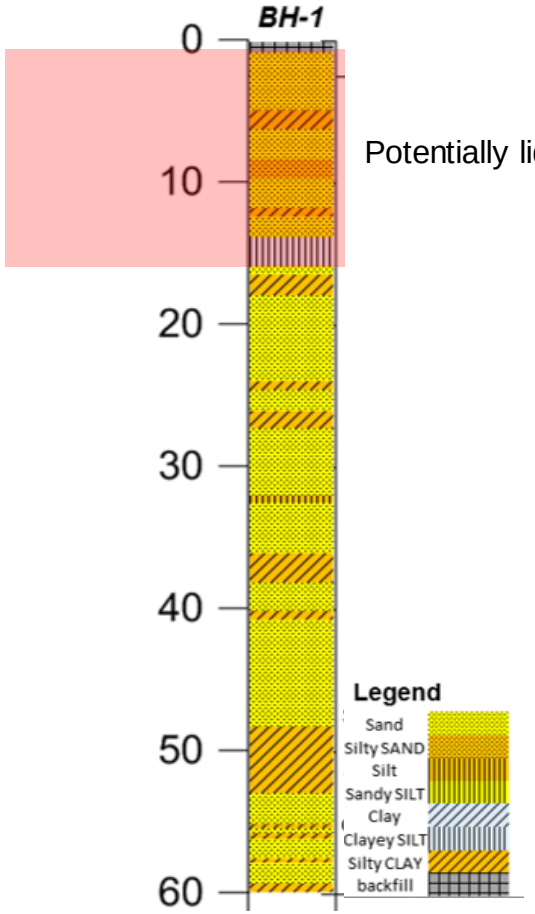


Combined methods – MASW, CPT, SPT



Combined methods – Preliminary liquefaction assessment





Summary and recommendations

- Liquefaction assessment is an actively evolving topic in science and engineering, and is a critical step to ensure a sound structural design and to mitigate the risk of liquefaction-induced damages
- All three in-situ methods discussed yielded generally consistent results for evaluating liquefaction resistance
- The choice of field test depends on the site conditions, extent of available data, and cost
- Performing a combination of the presented field methods will result in a higher confidence level and will aid in generating a comprehensive subsurface profile

Relevant GHD projects

Project:
Proposed 1200 MW Coal-Fired Power Plant

Client:
Atimonan One Energy, Inc.

Scope:
Geotechnical concept study for the proposed main power plant and additional proposed ash storage expansion areas

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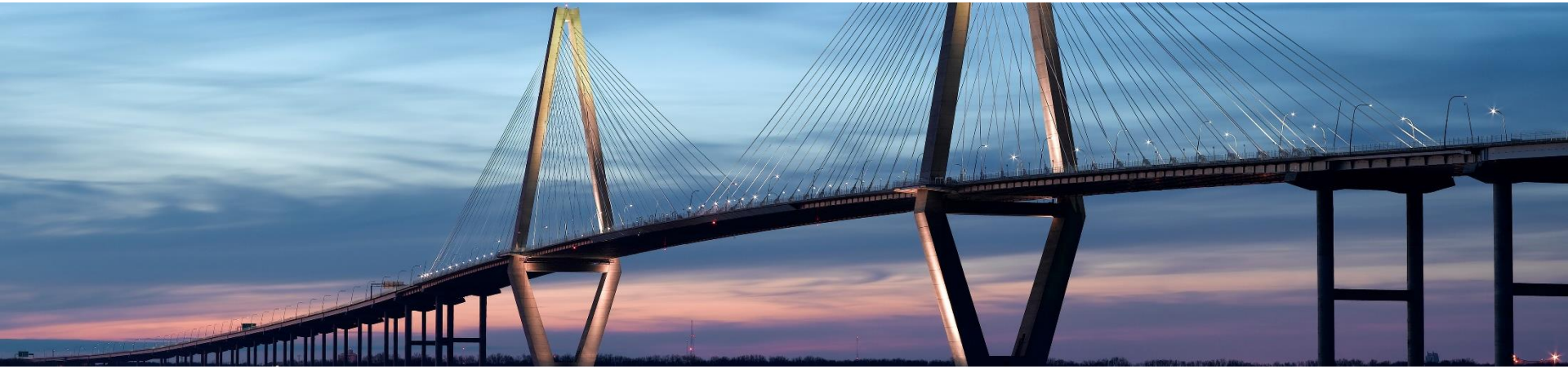

Project:
Inter-island Bridge

Client:
Confidential Client

Scope:
Geotechnical assessment of a proposed inter-island link including bridges, viaducts and causeways

Relevant GHD projects

Project:
Didipio Gold and Copper Mine Project

Client:
OceanaGold (Philippines), Inc.

Scope:
Design, construction supervision and management of a tailings storage facility

www.ghd.com