Quality Control of Vibro-compacted Carbonate Sands by means of CPT

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OUTLINE

HYDRAULIC FILL	REQUIRE-MENTS	CARBONATE SAND
QUALITY CONTROL	CASE SARB	CONCLU-SIONS / CONSIDE-RATIONS

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Large land reclamation works – Hydraulic Fill

Large land reclamation works – Hydraulic Fill

- Massive sand placement by dredging equipment
- Quality depending on local availability (fines content, mineralogy, …)
- Quality in part depending on dredging technique and segregation in reclamation
- (Relative) Densities depending on installation method and above or below water installation

Requirements

- Material
  - PSD: size and amount of large particles; fines content; Uniformity
  - Mineralogy (e.g. carbonates content)
  - Plasticity
- Relative density / Compaction
  - Minimum relative density; may be different above and below water; often higher in top 1 or 2 m
  - Target q_c-line
  - Liquefaction resistance FoS_L
- Shear strength: friction angle φ’
- Bearing Capacity under defined loads on foundations
- Settlements
  - Overall settlements under (service) loads / Differential settlements
  - Residual settlements (consolidation of natural layers; secondary settlements)
  - Earthquake induced settlements

Requirements → Ground Improvement

Ground improvement techniques typically used for granular fill

- Vibroflotation
- Dynamic compaction
- RIC
- HEIC
- Roller compaction
- Stone columns

Technique selected depending on fill material characteristics, layer thickness and on requirement

QA: Measure execution parameters!

Carbonate sand

Calcareous sand or Carbonate sand

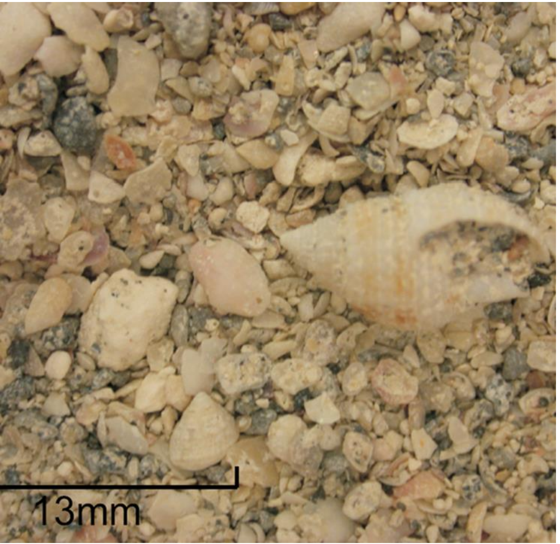
- Sand with (broken) shells
- Sand particles are microscopic small shells or shell debris
- Sand particles are porous
- Sand particle density: test material or porous individual particles?
- Up to 100% $CaCO_3$
- Minimum $CaCO_3$-value?

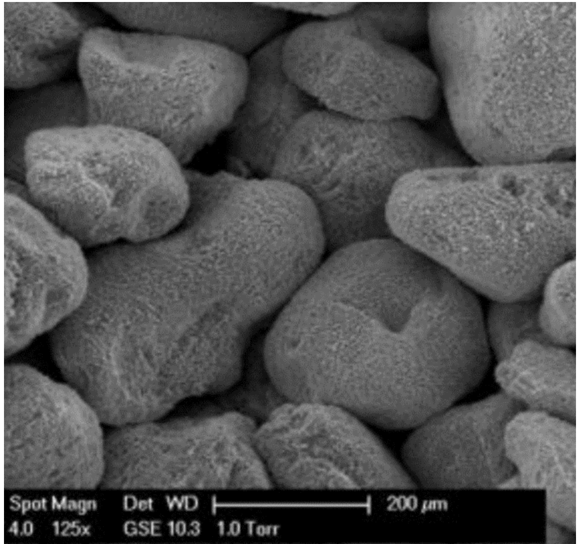
Occurs in many places in the world

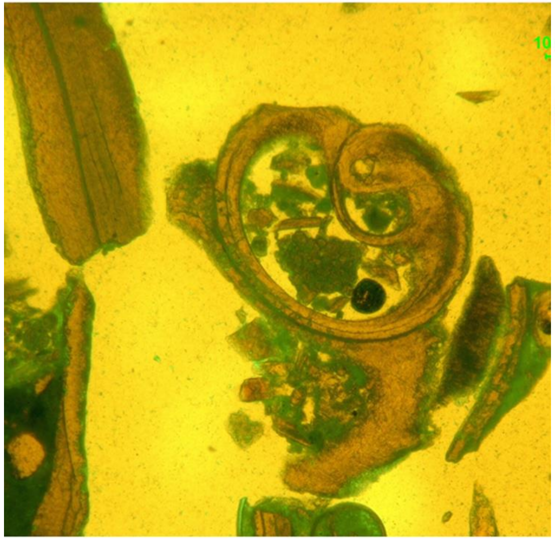
Is locally available and has to be used

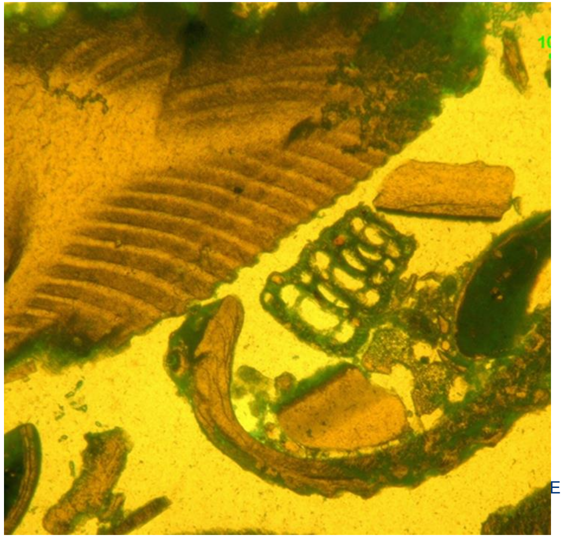
Carbonate sand

Many different calcareous or carbonate sands are found in the world!









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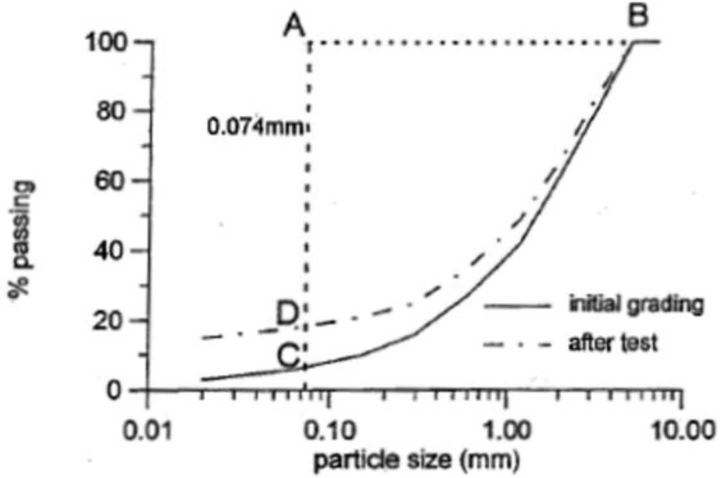
Calcareous sand

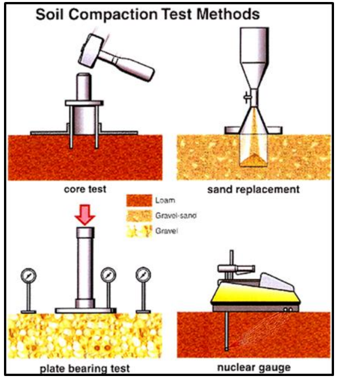
Some consequences

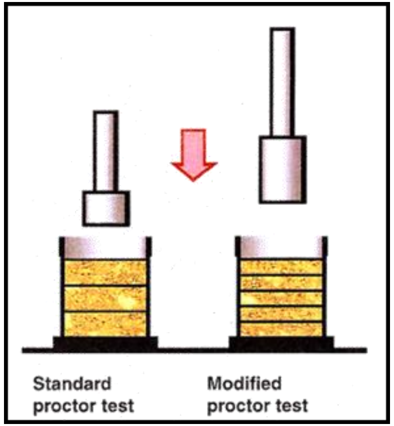
- Crushable material
- Effect on compaction: zone of influence / change in PSD / less permeable mantle around the probe
- Effect on testing: CPT / MDD / other?
- How to interpret CPT?
- How to perform lab testing: proctor vs vibratory table?
- Min and Max densities are lower in absolute value compared to silica sand: gives ‘uncomfortable’ feeling
- Effect on shear strength : angularity: φ’ >>
- Effect on stiffness : lower stiffness
- Effect on liquefaction potential : + or - : is unclear
- Often fines are mineralogically the same non plastic material – product of particle degradation

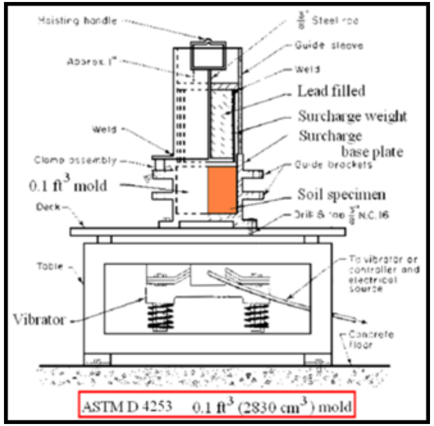


total breakage, Bt = area BCDB
breakage potential, Bp = area BCAB
relative breakage, Br = Bt/Bp

Quality Control *with calcareous sand*







Sampling and shallow testing

- ► PSD – attention not to further desintegrate the material
- ► In situ density – Sand replacement method
- ► Defining MDD – No dynamic tests; prefer vibratory table according to ASTM

Deep testing

- ► CPT with Shell Correction Factor
- ► BH with SPT – SCF??? No literature available

Further evaluation based on CPT

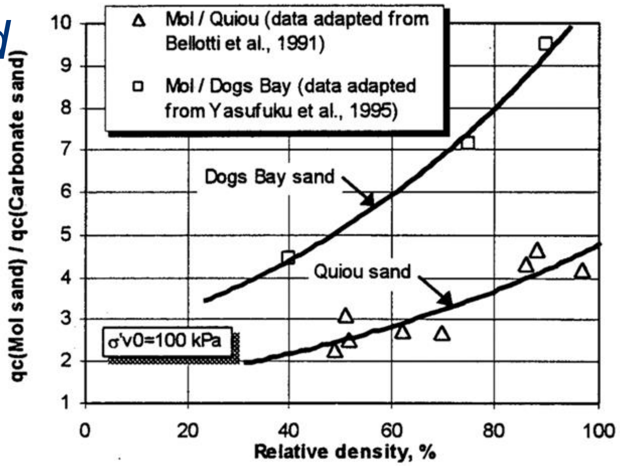
- ► Material type and layering
- ► Relative density
- ► Liquefaction assessment

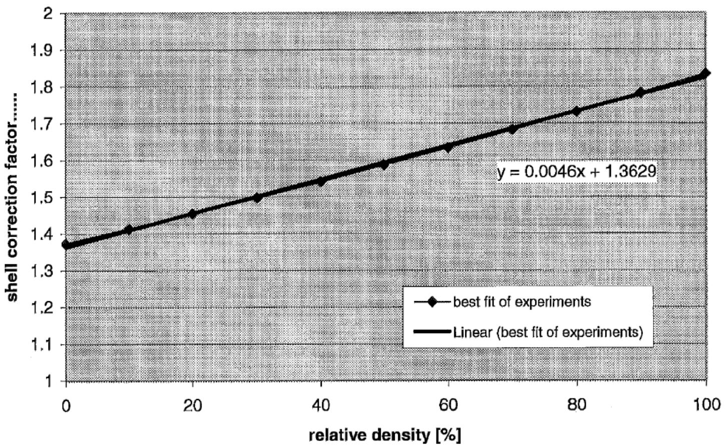
Quality Control *with calcareous sand*

CPT and Shell Correction Factor

- SCF = $q_{c,silica}$ / $q_{c,carbonate}$
- Has been demonstrated by multiple researchers
- Depends on Carbonate sand type
- Depends on Relative density
- Depends on stress state
- Depends on Carbonates content

- Need for project dependent calibration
- Use of a constant value of 1.3 is not correct

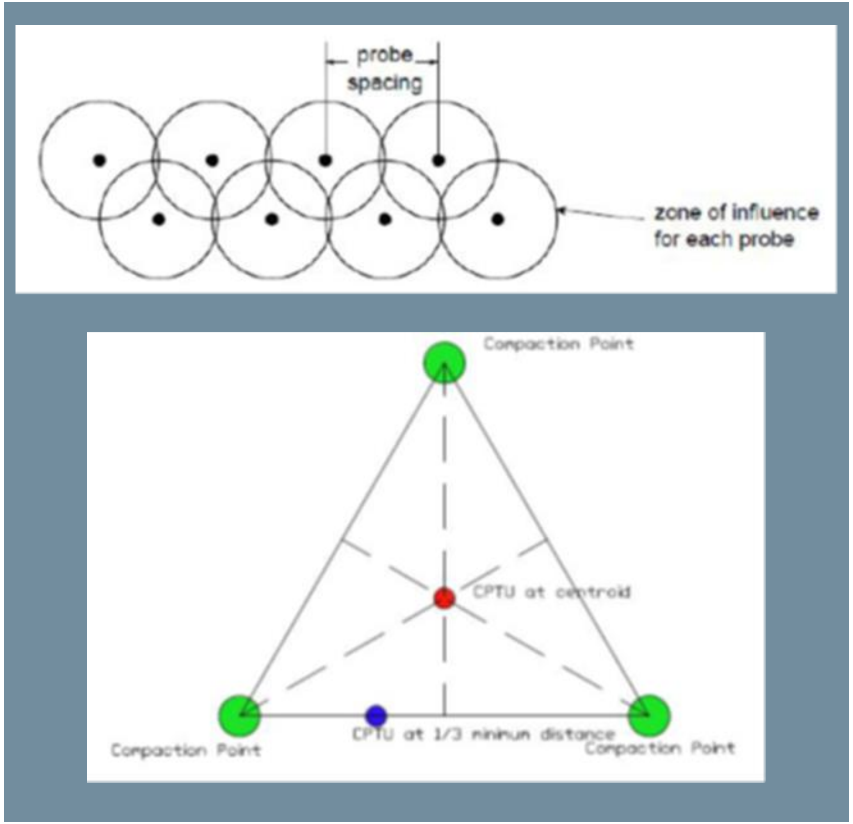




Quality Control *with calcareous sand*

QC CPT in Vibroflotation practice

- Compaction in triangular grid
- Quality control by means of CPT: where to perform?
- One CPT in center of grid: ‘worst’ location’
- One CPT at 1/3 distance between compaction points: ‘best location’



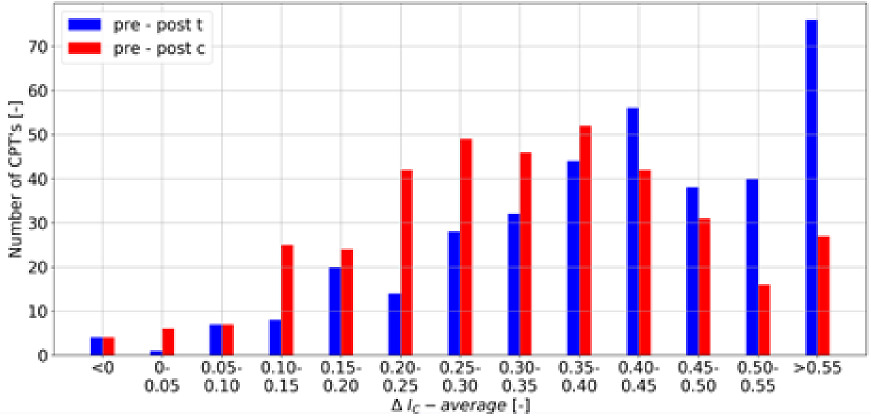
Remark: Quality assurance during VC execution; measure all execution parameters – required power at end of each compaction level is good control parameter

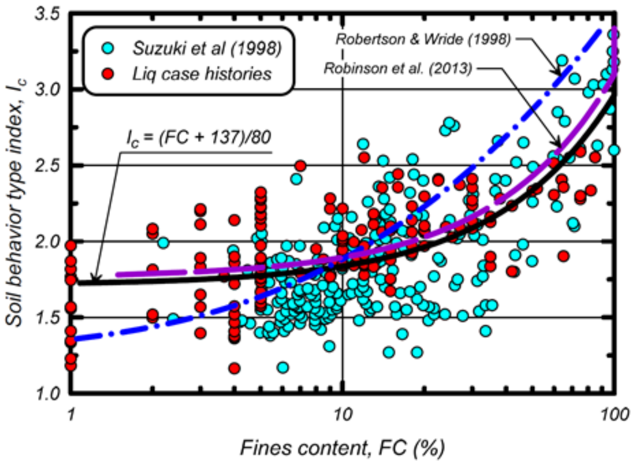
Quality Control *with calcareous sand*

Evaluation of CPT's

- Analysis of CPT result – presence of ‘unsuitable’ layers in the fill
- Allowable ‘inclusions’:
  - Max layer thickness: 0.2m to 0.3m
  - Sum of all inclusions: max 10% to 15% of total fill thickness / sometimes not allowed above the water table or in top x m
  - No influence on settlement and BC requirements
- CPT-handling for further analysis
  - Horizontal averaging; sometimes allowed only for relative density, not for liquefaction analysis – is considered very conservative approach
  - Vertical running averaging (over 1m or 0.5m): is generally allowed but discussion wrt averaging height
- SBT I_c parameter for fines content: not reliable! Always sampling needed for ‘contractual’ evaluation of fines content

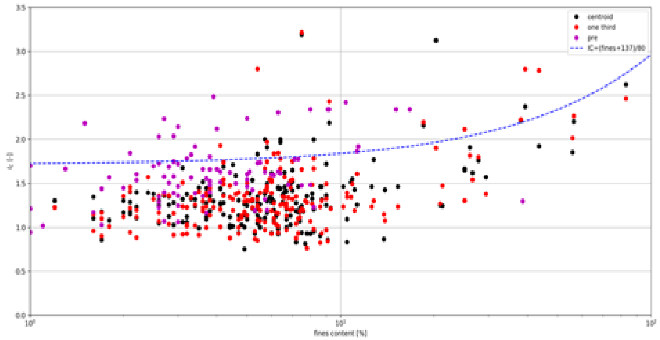
Quality Control *with calcareous sand*





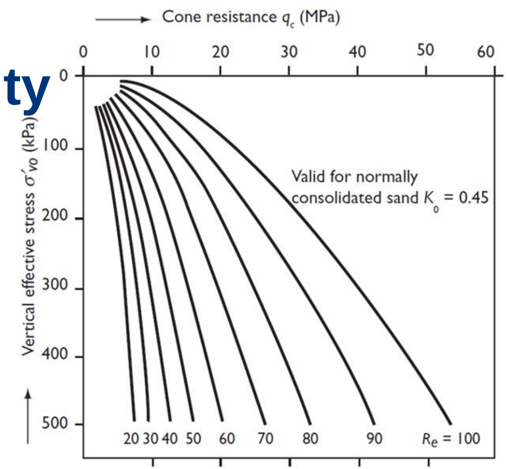
CPT analysis for Soil Behavior Type I_C

- No fully reliable link with fines content; is called 'apparent' fines content by Robertson
- Gives different result when one compares the I_C from pre to post compaction CPT's
- Important factor for automatic liquefaction assessment
- One should combine pre compaction I_C with post compaction CPT: how to do this?



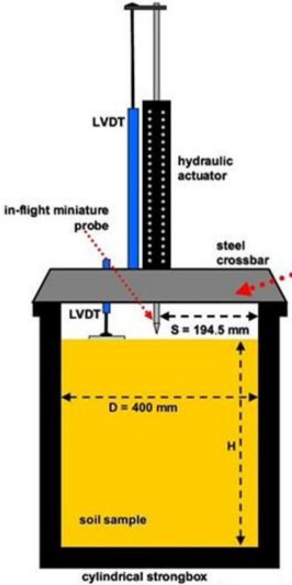
SARB ISLANDS CASE STUDY

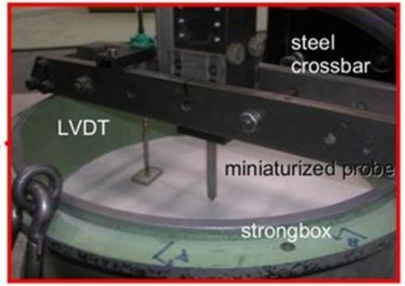
Case study: how to define relative density



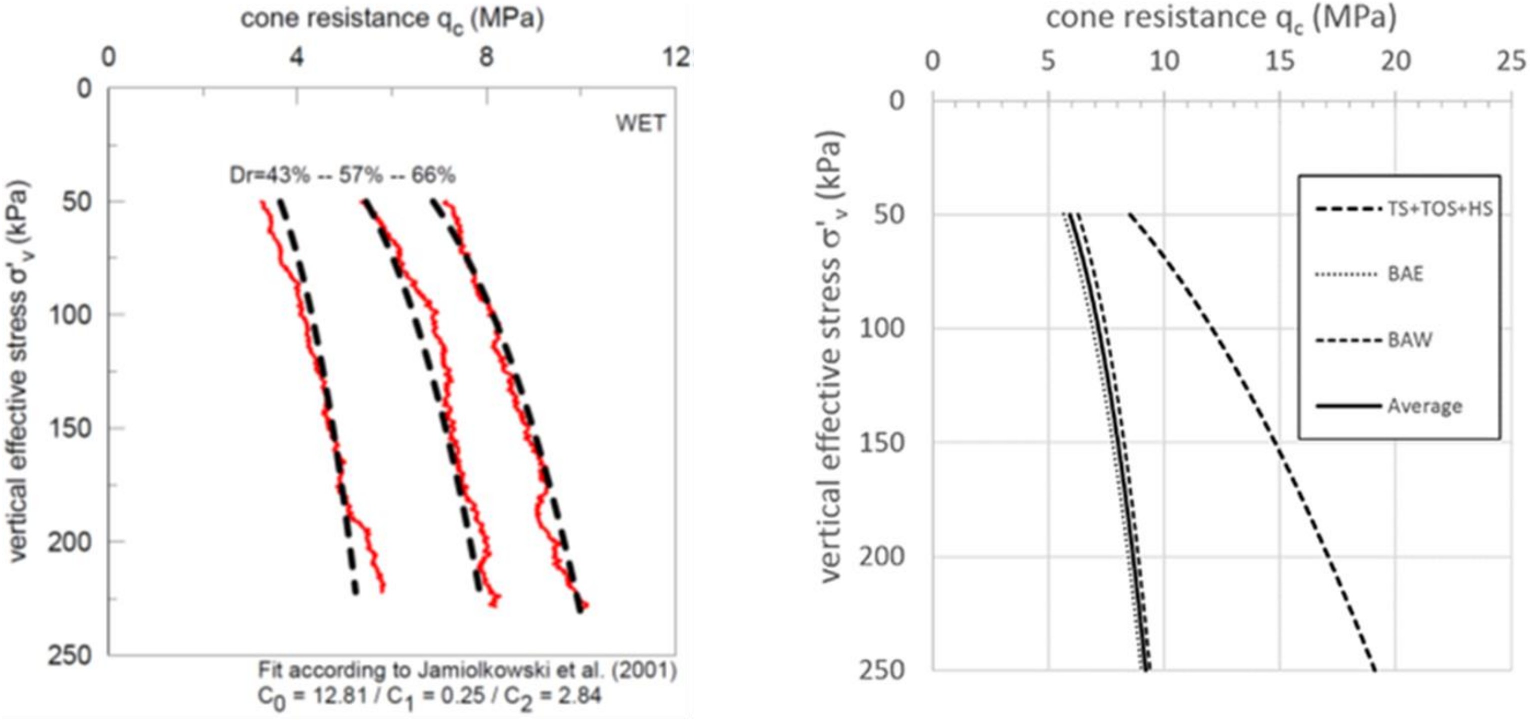
How to define relative density?

- Typical relative density correlations (Baldi, Jamiolkowski, …) not valid for carbonate sand and different correlations show large scatter
- Use of SCF is a solution, but we went for more correct approach: site specific calibration
- Calibration Chamber tests at ISMGEO
- Centrifuge testing: CPT in the flight: cover the whole stress range in the flight
- Testing of 3 different relative densities
- *Practical test procedure for quick and economical testing during project execution*



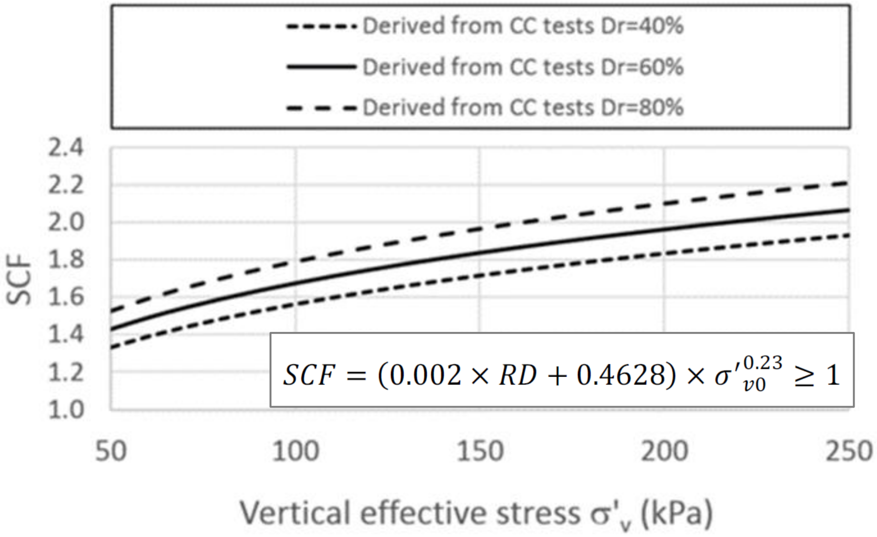


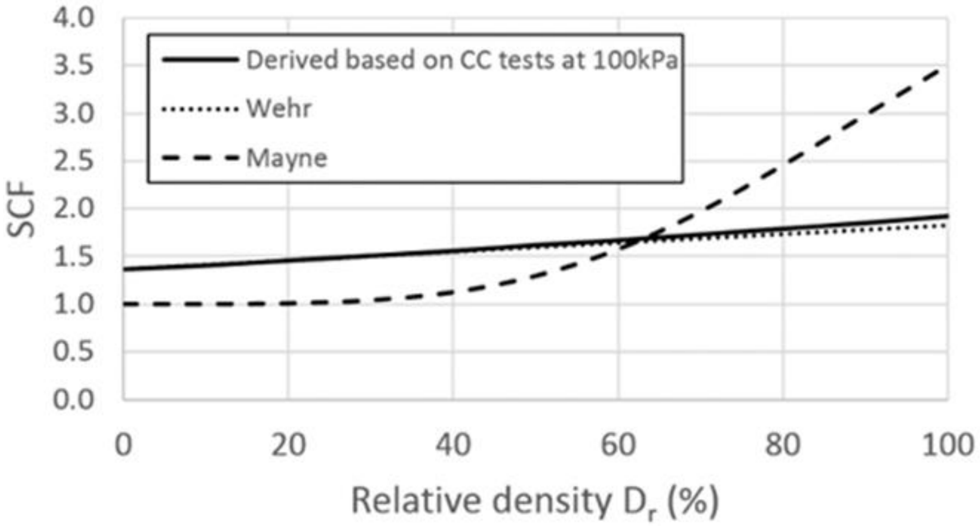
Case study: Calibration chamber test results



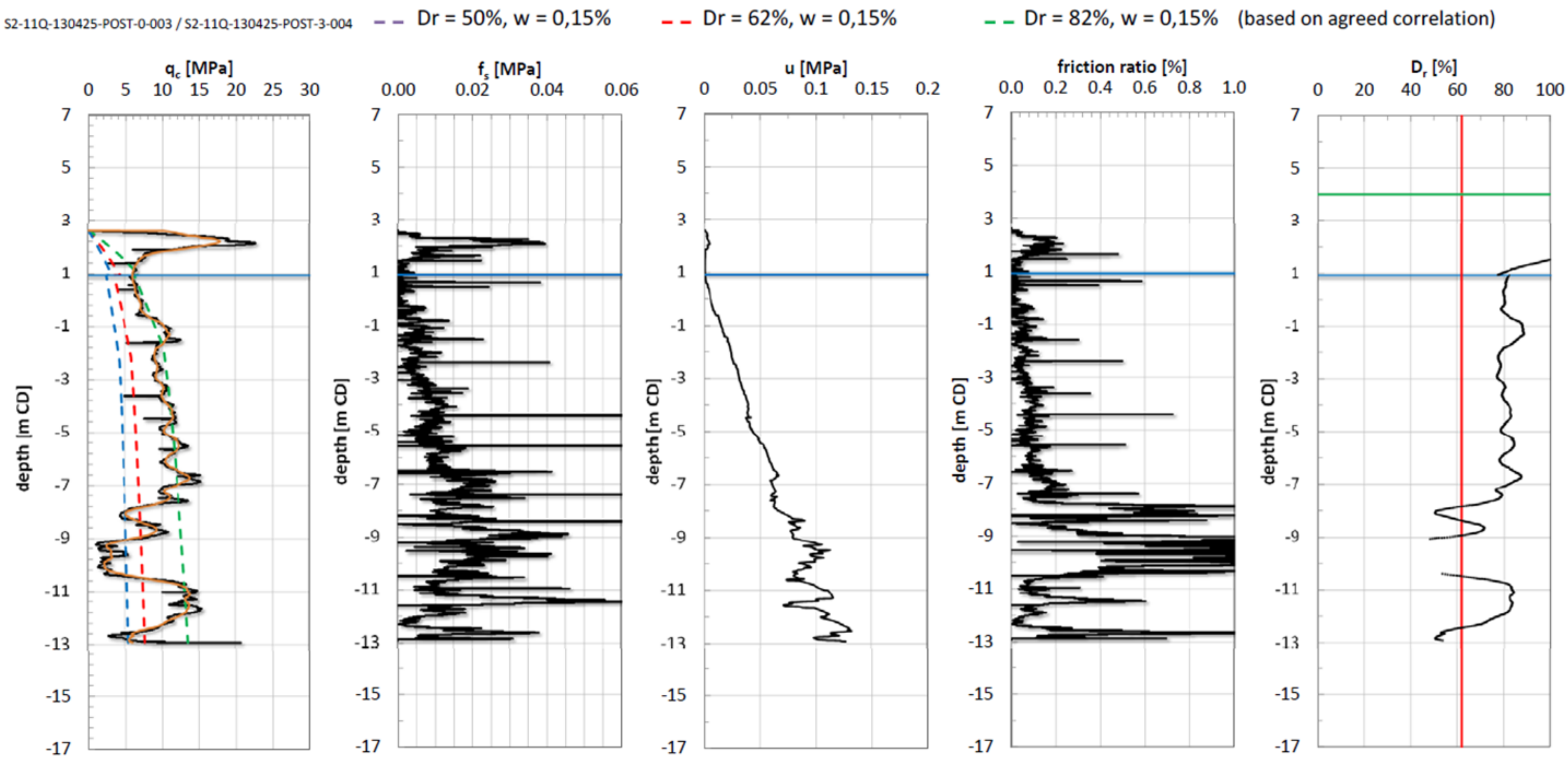
Case study: SCF

- Relative density definition is OK with site specific calibration: discussion solved
- Practical approach for liquefaction assessment: with SCF
- Is dependent on the relative density formula used (Jamiolkowski et al, 2001 is taken as reference)
- Is dependent on the relative density and stress level
- What about dependence on PSD, C_u or carbonates content? Mayne: when CC > 42% independent



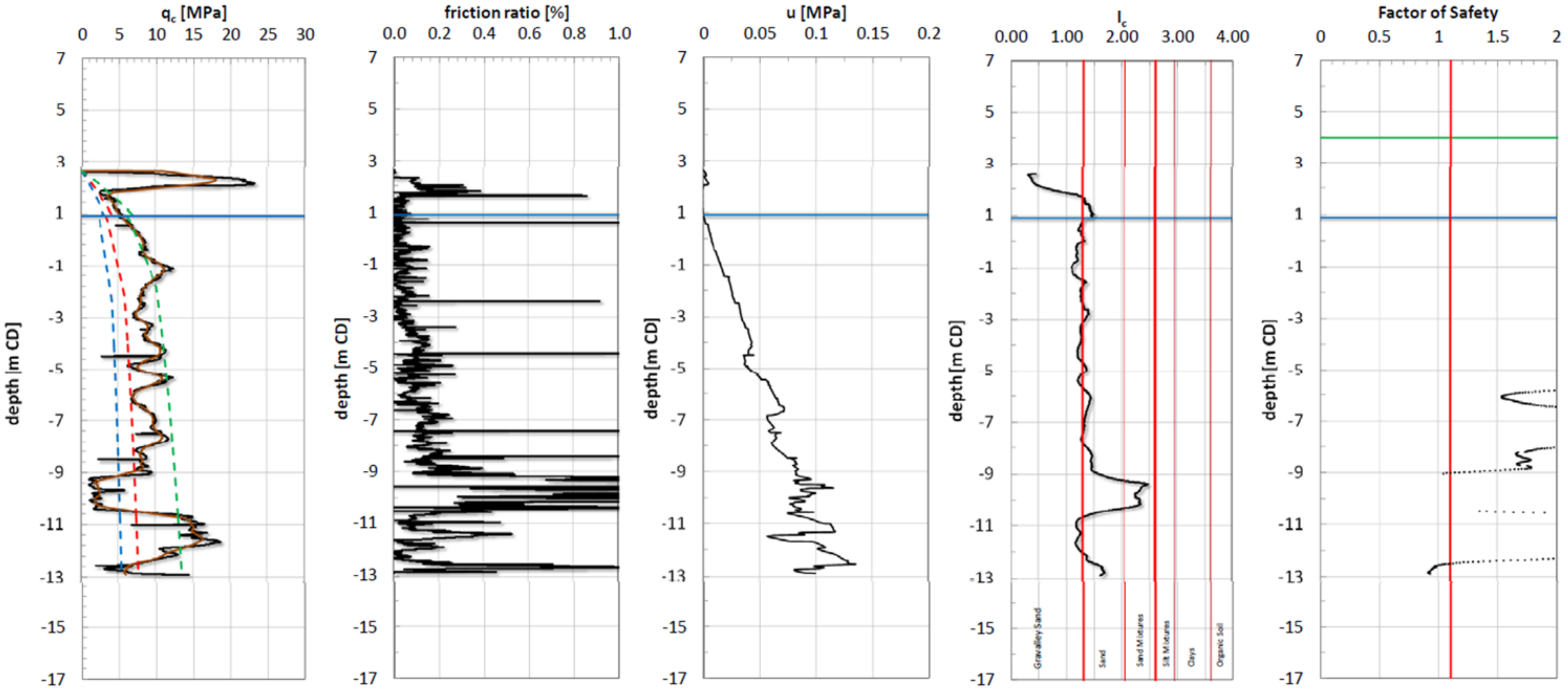


Case study - Post compaction CPT evaluation – relative density



Case study - Post compaction CPT evaluation – Liquefaction

S2-11Q-130425-POST-0-003 Dr = 50%, w = 15% Dr = 62%, w = 15% Dr = 82%, w = 15% (based on agreed correlation)



Conclusions / Considerations

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- Mineralogy of the reclamation material is important: need for $CaCO_3$-content!
- Adapted quality control methods for specific crushing behavior
- Use of SCF: remains a point of discussion with client/consultant but also from theoretical point of view (for different reasons)
- Site Specific correlations for relative density will help for RD, not for liquefaction assessment
- Remain realistic when evaluating such large earthworks below and above the water table: allowance for ‘unsuitable’ inclusions; certain margin on ‘non-conformity’ is unavoidable unless ‘clean’ Borrow Area is found
- Preference for ‘Performance Requirements’: do not only focus on material testing, but overall behavior testing (e.g. zone load tests, embankment tests, …)
- When one wants to avoid the use of SCF for liquefaction assessment: more advanced testing such as cyclic TX or cyclic DSS or in situ testing by means of Seismic CPT, PMT or DMT – need for further research in these fields with calcareous sands
- Liquefaction assessment: : why is Liquefaction Potential Index not used in practice (e.g. to overcome issues with limited thickness failing silty sand layers)?
- Engineering Review / Engineering Judgment remains key in these projects

Thank you for your attention