CPTs for High Risk Projects

Topics

- ❑ Current practice
- ❑ The new ISO for CPTs (BS EN ISO 22476-1)
  - Specifying the CPT for high risk ‘projects through ‘Application Classes’
    - – Equipment
    - – Procedures

Risk and Methodology

What is a high risk scenario?

For ground investigations, risk to data quality it may be a function of:

- ❑ Methodology (Getting the right data)
- ❑ Ground conditions (testing methodology unsuitable for the materials?)
- ❑ Time and space restrictions (re-tests impossible?)
- ❑ Optimum design solution changing (is the data still relevant?)

Only the methodology can be controlled to manage the risk by considering the others.

This presentation will look at how risk can be managed through appropriate methodology and the new ISO standard for CPT testing.

Current Practice

The need for an application/risk driven CPT testing:

- CPT contractors attempt to balance the interests of maximising performance/meterage and conforming to best practice procedures in line with the clients perceived interests.
- The test standards contain a degree of freedom in selecting methods and contractors have (often) tended towards the ‘middle ground’ in order to optimise quality vs. production (given no specific instruction). This has resulted in a new testing standard:

'ISO ***Common Practice*** for CPTs’.

Current Practice

Current Practice

- Ultimately the clients aim is to efficiently reduce uncertainty in ground conditions…so maximising meterage is often appropriate. However, it should be done with appreciation of the likely consequences for the applicability of the data.
- The Eurocode BS EN ISO 22476-1 offers a framework for testing methods optimized for 'application classes' to address this**…"the required accuracy is meant to be a function of what the results are to be used for".**

BS EN ISO 22476-1 CPT Testing

The new ISO is a performance based standard, rather than the more common prescriptive, method based standard used for geotechnical testing. This style allows the standard to focus on ‘application classes’ with equipment and methods that are tailored to the intended interpretation.

‘Application Classes’ are based on:

- The test ‘type’ (CPT/CPTu),
- Minimum measurement ‘accuracy’ (e.g. 35 kPa or 5% MV) for each sensor
- Range of materials encountered (soft to hard/very dense or a mixture)

...Then, permissible interpretation methods are defined for **specific soil type categories** within the application class (Profiling, material identification and definition of soil parameters)

Best illustrated with an annotated diagram...

EN ISO 22476-1 'Application Classes'

Application class	[illegible]	[illegible] parameter	[illegible] accuracy[a]	[illegible] between measurements	Use: Soil[b]	Use: Interpretation / evaluation[c]
1	TE2	Cone resistance	35 kPa or 5 %	20 mm	A	G, H
		Sleeve fr[illegible]	[illegible]			
		Pore pr[illegible]e	10 kPa or 2 %			
		Inclination	2°			
		Penetration length	0,1 [illegible] 1 %			
2	TE1 TE2	Cone resistance	100 [illegible] 5 %	[illegible] mm	[illegible]	[illegible]
		Sleeve friction	15 kPa or 15 %		B	G, H
		Pore pressure[d]	25 kPa or 3 %		C	G, H
		Inclination	2°		D	G, H
		Penetration length	0,1 m or 1 %			
3	TE1 TE2	Cone resistance	200 kPa or 5 %	50 mm	A	G
		Sleeve friction	25 kPa or 15 %		B	G, H*
		Pore pressure[d]	50 kPa or 5 %		C	G, H
		Inclination	5°		D	[illegible]
		Penetration length	0,2 m or 2 %			
4	TE1	Cone resistance	500 kPa or 5 %	50 mm	A	G*
		Sleeve friction	50 kPa or 20 %		B	G*
		Penetration length	0,2 m or 2 %		C	G*
					D	G*

NOTE For extremely soft soils, even higher demands on the accuracy can be needed.

[a] The allowable minimum accuracy of the measured parameter is the larger value of the two quoted. The relative accuracy applies to the measured value and not the measuring range.

[b] According to ISO 14688-2 [1]:
- A homogeneously bedded soils with very soft to stiff clays and silts (typically $q_c < 3$ MPa)
- B mixed bedded soils with soft to stiff clays (typically $q_c \leq 3$ MPa) and medium dense sands (typically 5 MPa $\leq q_c < 10$ MPa)
- C mixed bedded soils with stiff clays (typically 1,5 MPa $\leq q_c < 3$ MPa) and very dense sands (typically $q_c > 20$ MPa)
- D very stiff to hard clays (typically $q_c \geq 3$ MPa) and very dense coarse soils ($q_c \geq 20$ MPa)

[c]
- G profiling and material identification with low associated uncertainty level
- G* indicative profiling and material identification with high associated uncertainty level
- H interpretation in terms of design with low associated uncertainty level
- H* indicative interpretation in terms of design with high associated uncertainty level

[d] Pore pressure can only be measured if TE2 is used.

Test type CPT/CPTu

CPT Sensor

Accuracy

Resolution

1: V. soft to stiff.............

2: Soft to v. dense..........

3: Soft to v. dense..........

4: Soft to v. dense..........

Soil catagories

A: V. soft to stiff

B: Bedded soft to m. dense

C: Bedded soft to v. dense

D: Bedded v. stiff to v. dense

Interpretation

G: Profiling and material type

H: Design/soil parameters

***:** High associated uncertainty (vs. low uncertainty)

EN ISO 22476-1 'Application Classes'

Some positives

- The elements that make up each application class provide a useful tool to specify a methodology with appropriate equipment and procedures for the expected stratigraphy or interpretation requirements. This has clear benefits in:
  - Economy of the testing method where 'best practice' for all soil types may not be necessary
  - Reducing the risk of obtaining unsatisfactory data
- Independent cone sensors can occupy different application classes, e.g. useful in very soft soils where the tip resistance (q_c) may have a lower accuracy than the dynamic pore pressure (u_2), where both can be used to estimate Su, OCR...
  - Taking this further, we could use a very high capacity cone (with lower sensitivity/accuracy) for achieving greater refusal depths, whilst using a sensitive pore pressure sensor (and best practice) for characterisation of critical soft soils.

EN ISO 22476-1 'Application Classes'

Some problems

- Accuracy
  - The accuracy of the measurement is required - not an uncertainty budget. That is, the in-situ measured value compared to the **TRUE** value.
  - In-situ reference soil measurements can't exist, so we presume the true value is the calibration force. However;
  - The transducer calibration, based on force, has nothing to do with knowledge of the soil-instrument interaction (e.g. influence of tolerances, inclination..) which we need to understand accuracy/uncertainty.
  - Work is ongoing to estimate accuracy/uncertainty.
- Contradictions e.g. "application class 1 is intended for soft to very soft soil deposits" then in the table is defined as "...very soft to stiff clays and silts".

EN ISO 22476-1 ‘Application Classes’

Why are application classes based on soil profiles?

The soil stiffness/density influences the measurement for example:

- ❑ Transient temperature effects on the strain gauge - 1°/MPa in sands (at the cone surface)
- ❑ The maximum resistance influences the measurement sensitivity/resolution of the instrument that can be used.
- ❑ Hysteresis and creep effects on the load cells
- ❑ Stiffer soils tend to push more dirt into the seals with act on the load sensors (observed in zero values).

The classes are defined by the soil profile **and** required minimum accuracy. So even if we decide a measurement has a low uncertainty we still might not be able to use it for design as we are limmited by the soil profile? We are given some guidance in Annex E:

“...with special equipment, procedures and [cone] temperature measurement... application class 1 can be achieved” [for soft soils interbedded in stiff/dense materials]

EN ISO 22476-1 'Application Classes'

What does "*special equipment, procedures and temperature measurement*" involve for soft to very-soft clays? Most likely:

- **Special equipment** - A low capacity (sensitive) cone, or, cone calibrated and amplified over a smaller stress range.
- **Procedures** - Temperature stabilising at the top of soft layers below coarse layers, or, predrilling. This also allows pre/re-saturation of the piezo sensor for accurate pore pressure and corrected cone resistance measurement.
- **Temperature measurement** – Measurement of temperatures in the cone body. This isn't available yet from the vast majority of manufacturers but we can compensate by calibrating the temperature stabilisation time in a soil medium.

There are many other quality procedures that can be employed – examples later on...

Improving on 'common practice'

For high risk projects it is advisable to specify tighter controls or 'best practice' on many aspects of testing in order to minimise uncertainty – especially in soft soils.

- These don't require any bespoke/unusual equipment but some cost time.
- Some are from the ISO, others are from the literature and experience.
- Some assist with estimating uncertainty/accuracy in lieu of a numerical accuracy limit required by the ISO application classes.

Note: 'Common practice' in the following tables is from my limited collective experience and doesn't necessarily apply in all cases!

Improving on ‘common practice’

Best practice options using commonly available test equipment:

Best practice	Cost	Why	‘Common practice’
Reduce friction sleeve tolerance (annulus ø ≤ cone ø + 0.2 mm).		Oversized sleeve has an end bearing effect, increasing measured resistance. (Thorp & Holtrigter 2014)	Oversized sleeve ø ≤ cone ø (or u2 filter ø) + 0.35 mm.
Piezo saturation using vacuum chamber/submersion method and preferably a pilot hole; or use of viscous saturation fluid for penetration through unsaturated soils. Melted glycerine is highly effective.	10 mins	Repeatable, accurate dynamic pore pressure results.	Saturation using a syringe and pre-saturated filters using a single viscosity fluid.
Pre-drill and pre-charge the pilot hole with water to saturated ground.	5 - 30 mins $ 0 - 50	Prevents piezo desaturation in unsaturated soils. Best results from standard piezo filter design.	Push saturated piezocones through unsaturated ground; Use of a ‘grease slot’ or low viscosity oil for desaturation resilience.

Improving on 'common practice'

Best practice	Cost	Why	'Common practice'
Perform dissipation tests to allow re-saturation of the pore-pressure sensor. Works best in soft soils soon as excess pressures rise, or under 90+ kPa hydrostatic.	5 – 15 mins per desaturation	Accurate pore pressure results; Offers a good control point in identifying reliable results.	Dissipation tests for re-saturation are believed to be uncommon.
Quick dissipation tests to verify drainage conditions and water table.	0.5 – 5 mins	Confirms drained / undrained / partially drained penetration and soil drainage type; Confirms drainage behaviour when compared to longer dissipations.	Sometimes undertaken. Often operator/client dependant.
Pre-drilling to soft soil strata	1 min/m + 10 mins	Enables the re-zeroing following stiff/dense strata; Substitute for a more sensitive cone.	Penetrate the entire profile in a single 'stroke'.

Improving on 'common practice'

Best practice	Cost estimate	Why	'Common practice'
Dissipation of frictional heat at the top of soft soil layers below coarse materials.	10 - 15 mins	Prevents transient temperature gradients affecting the load cell transducers in the critical low stress range.	Generally not undertaken unless specifically requested, or evidence of measurement error is observed.
Pre-test temperature stabilization to ground temperature	5-10 mins	Prevents transient temperature gradients occurring in the cone. Accurate zero values.	Undertaken on a case by case bases, generally only for very soft ground conditions.
Post-test zero values for both cleaned and uncleaned conditions; both taken at ground temperature.	2-5 mins (cone dependant)	The difference in cleaned and uncleaned zero values indicates the relative influence of dirt in the seals affecting the sensors, and zero load drift in the load cell transducers.	Only cleaned or uncleaned values are taken. Generally uncleaned.
Cone relaxation prior to taking post test zero values.	5 mins	Dissipation of suction stresses following cone extraction	Not done.

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Improving on 'common practice'

Best practice	Cost estimate	Why	'Common practice'
Use of more sensitive cones for soft/loose soils.	1.5 mins per m depth to layer.	Higher sensitivity and lower calibration uncertainty	Use of high capacity cones to maximise depth potential in all scenarios.
Selection of a cone diameter with an appropriate zone of influence.		The zone of influence may mask very thin layers or accentuate transition zones.	The cone is generally selected based on robustness to maximise the refusal depth.
Calculating cone pressure resistance using the actual cone ø		Cone wear will result in different projected cone area.	Not done for conservatism
Corrected cone resistance using the actual cone ø not the nominal ø.		Cone wear will result in an area ratio that is different from the nominal value.	Not done for conservatism

...and more

None are compulsory (ISO "shall"), but all can be effective in improving the quality of results and estimating 'accuracy', important in soft to very-soft soils.

Improving on 'common practice'

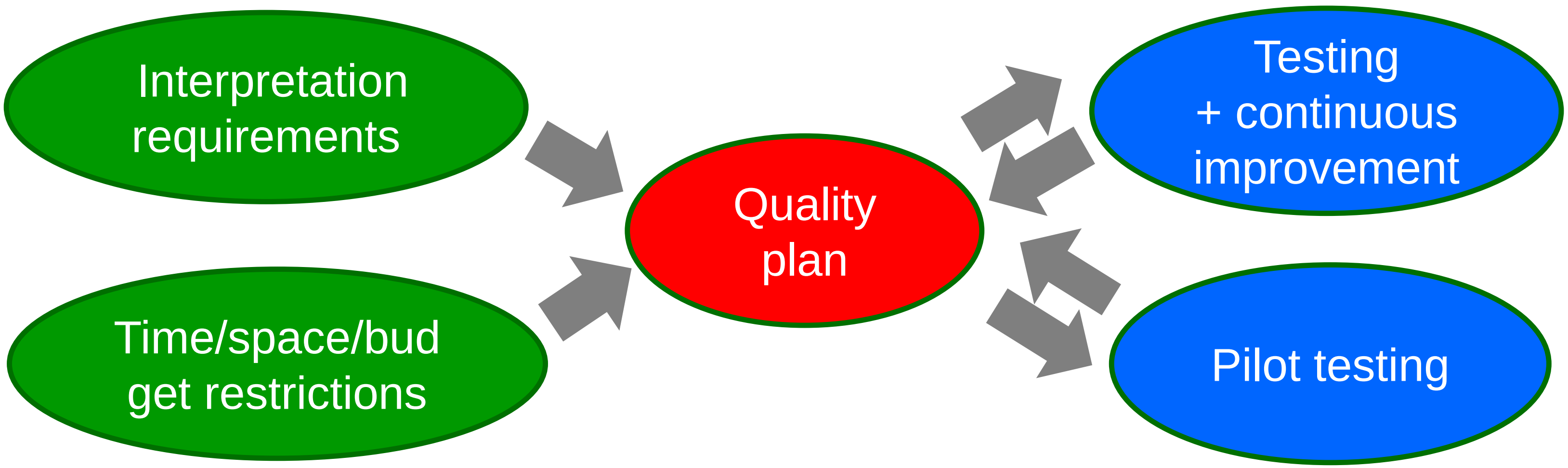
Why is 'common practice' so common?

- The 'common practice' CPT often provides remarkable repeatability a reproducibility with essentially no intervention in the methodology from the client.
- This approach is often carried over to high risk settings where a more informed consideration of methodology is required.
- If there is no impetus from the specifier then the 'middle ground' approach prevails and the results may not be suitable for the application.

CPTs should perhaps be approached in the same way as sampling, not other penetration tests (SPT, DPT…). i.e. Decide on the appropriate method and desired class.

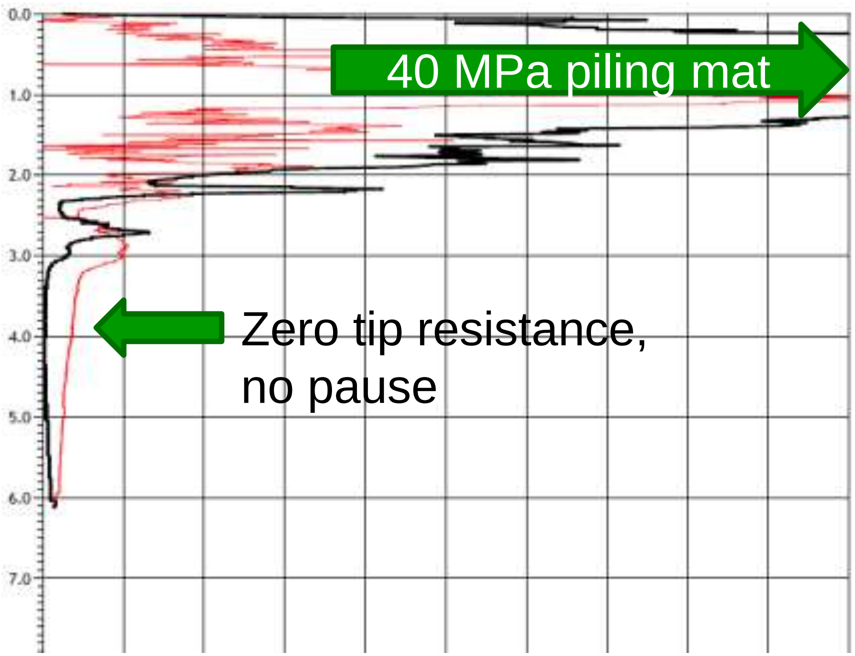
Improving on ‘common practice’

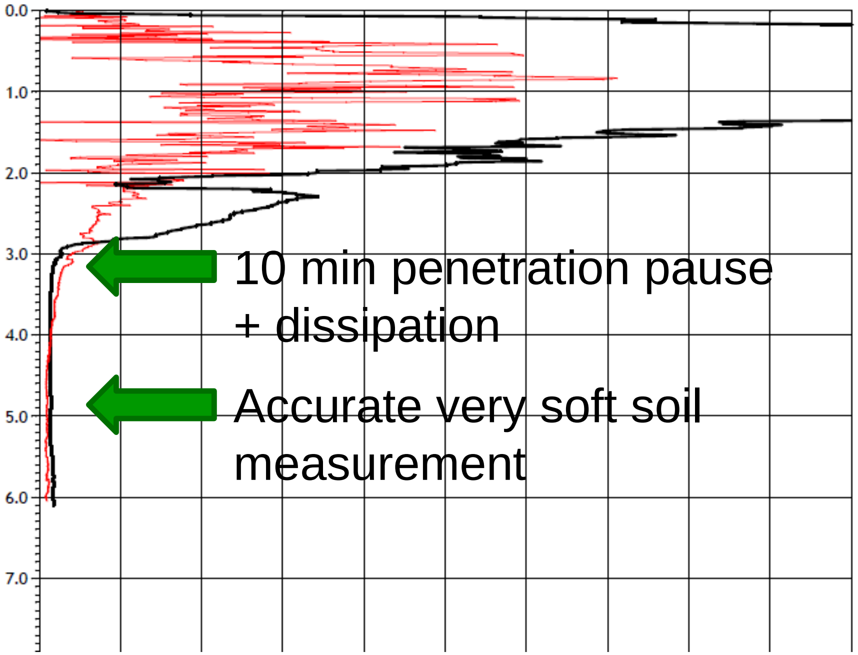
An ideal risk/application based approach



With time and space restrictions pilot testing and continuous improvement is difficult and a conservative methodology is required.

Example: Temperature stabilisation

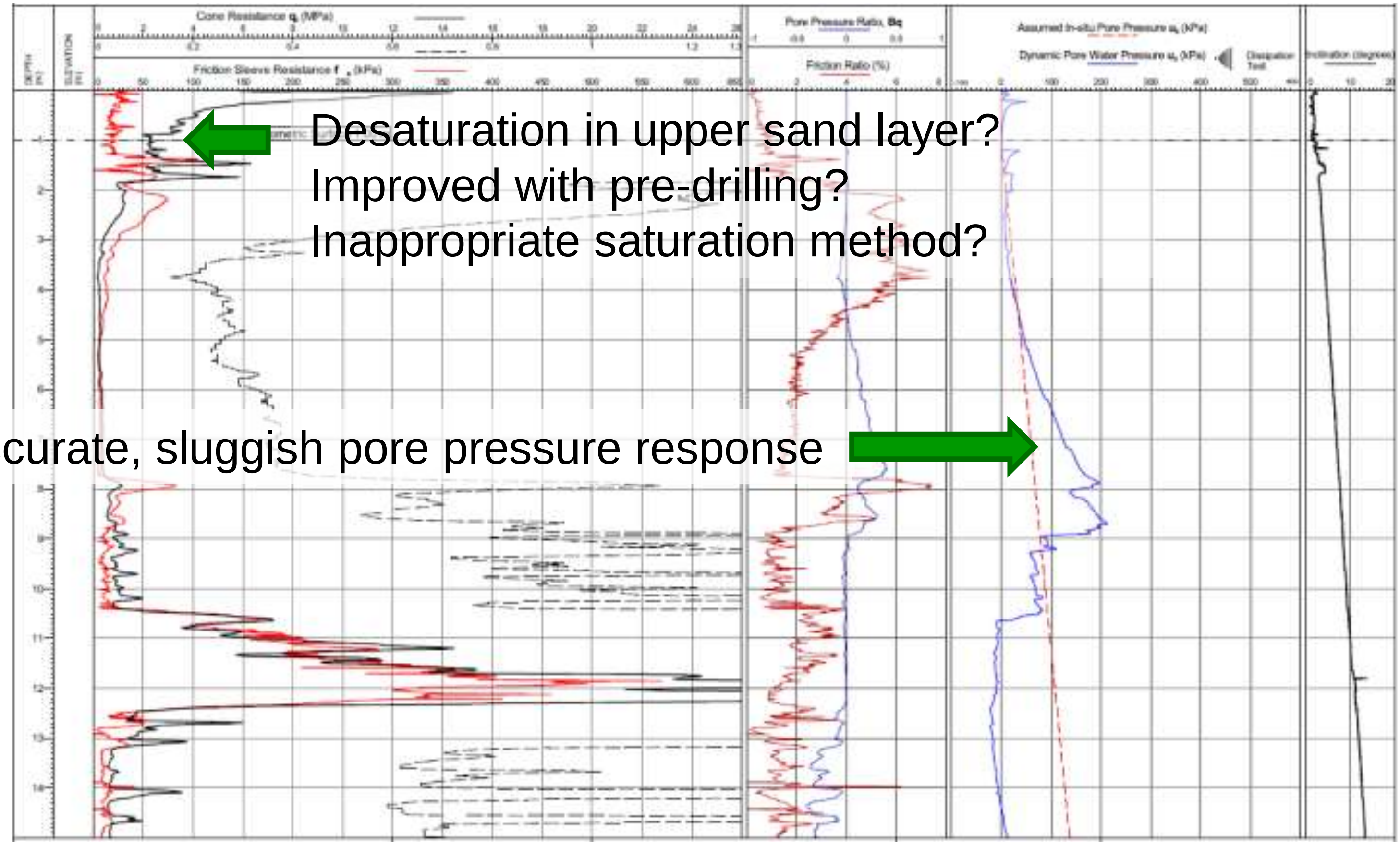




- ❑ Very short quality procedure, infinitely more accurate data for very soft soils

However, if no interest in the soft soils then this procedure could cost 1nr CPT/day and add to uncertainty elsewhere

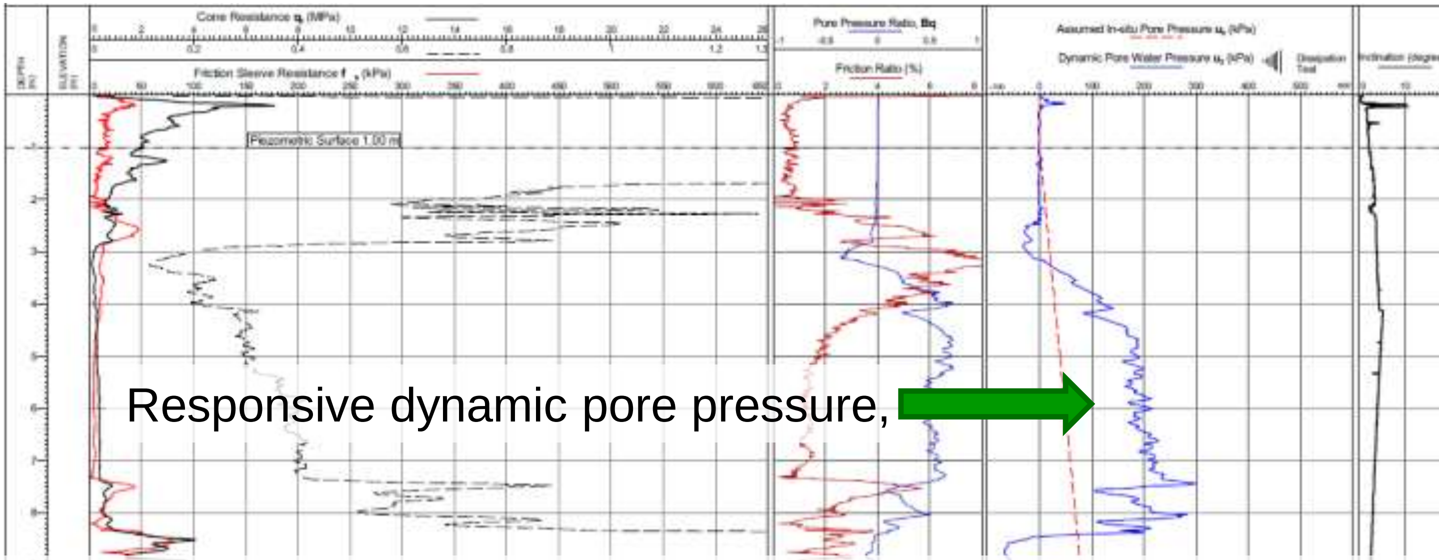
Example: u_2 pore-pressure response



Desaturation in upper sand layer?
Improved with pre-drilling?
Inappropriate saturation method?

Inaccurate, sluggish pore pressure response

Example: u_2 pore-pressure response



In this case, the client decided not to sacrifice production by pre-drilling to saturated ground. A potentially risky approach if pore pressure data is later needed for:

- Accurate corrected cone tip data (q_c => q_t).
- Su (+ comparison to Su from cone tip)
- Phi
- Material type, drainage characteristics

Thank You

Questions?