Recent advances in the understanding of Augercast piles and Displacement Augercast piles and impact on their design.

ir Maurice Bottiau – Franki Foundations

Recent advances in the understanding of CFA piles and Displacement AC piles and impact on their design.

Content

- AUGERCAST PILES CONSTRUCTION
- RECENT ADVANCES IN MONITORING AND TESTING OF AUGERCAST PILES
- CODES AND DESIGN OF AUGERCAST PILES
- HOW CAN CODES AND TECHNOLOGICAL EVOLUTION BE LINKED WITH EACH OTHER?

AUGERCAST PILE CONSTRUCTION

How do execution parameters impact pile performance?

Augercast piles Construction

Dramatic evolution

- CFA are extensively used worldwide (24%)
- Larger, bigger, deeper
  - Increasing complexity of systems and execution details,
  - Larger dimensions and ranges of depths or capacities which were never reached before.
  - Urban / Environmental (e.g., avoidance of pile driving noise & vibration)
  - Seismic or other high lateral demands
- The impact of electronic measurement devices, machine learning, automated installation
- Increased use of load testing, integrity testing and QA/QC
- Recent research on materials

But still we sometimes miss a correct understanding of some fundamental issues of the pile installation process.

Construction CFA/DD

Existing systems and equipment

- « Standard » CFA
- « Upgraded systems » and/or proprietary : Starsol, PCS, ..
- Systems with large stem (so called partial displacement)
- Cased augercast
- Screw piles/DD: several systems

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Construction CFA (Augercast)

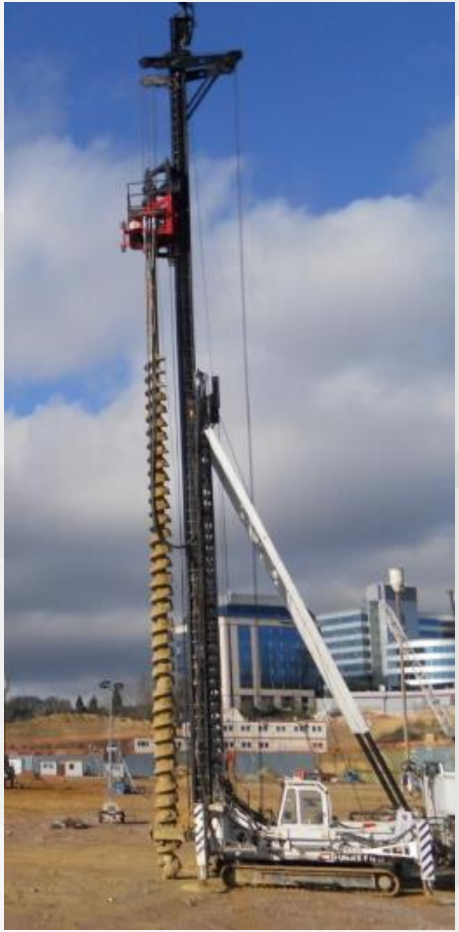
Standard CFA piles

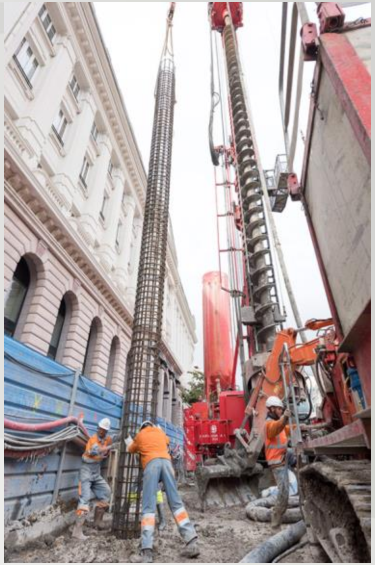
- « standard » CFA :
  - 300 to 600 mm (12 to 24 inches)
  - length 20.00 m (70 feet),
  - rigs 10 to 15 Tm (75.000 to 110.000 lbf ft)
  - limited crowd
- large risk of soil decompression
- Large variations of practice regarding the type of equipment and the proper monitoring of pile execution
- Impact on installation factors vary!

Construction CFA (Augercast)

Upgraded systems

- Increased penetration rate (due to increased installed power – higher torques up to 30 Tm (220.000 lbf ft) /pull down up to 20 T (45 kips)
- Large diameters : up to 1200 mm (48 inches), even more
- Long piles : more to 30 m (100 feet) (even 45 m-1500 feet)
- Concreting under pressure resulting in enhanced shaft friction; use of special plunge tube.
- Full monitoring of pile installation





CFA piles (augercast)

Technological issues

- New limits are reached (1500 mm – 50 m)
- Installation particularities:
  - Most common issue related to over-augering and pile integrity (see below)
  - Installation of reinforcement
  - Concrete quality and workability (see above)
- How do we account for the local soil disturbance?
  - Screwing ratio $SR = \mathrm{n}.\rho/$ V

Pile construction

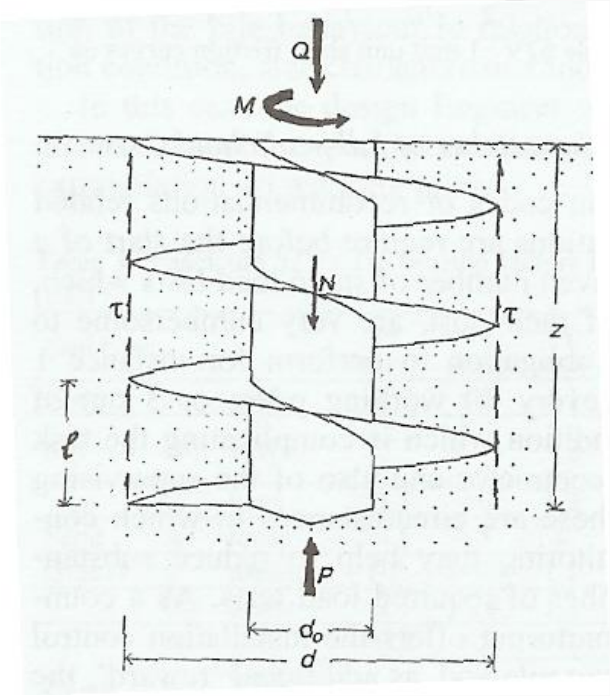
Reinforcement : new record (23/09/2020) by Soletanche Bachy

https://youtu.be/3cS-e1myxSI

- Starsol ® pile diam. 800 mm
- Length : 50,00 m
- Reinforcement introduced full length after concreting
- Concrete with special mix including Starsolithe-R

Pile construction

Over-augering



Mechanism of over-augering (Viggiani, 1993)

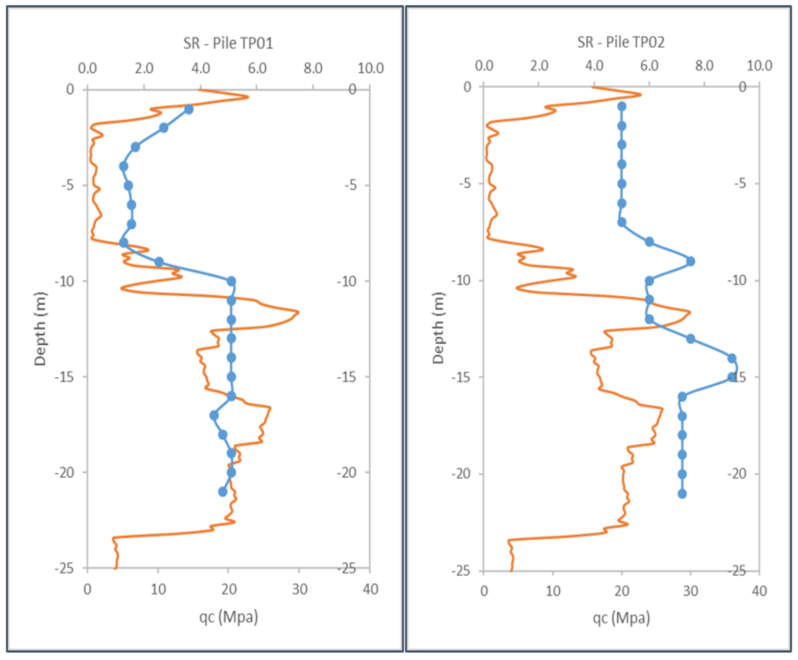
- Screwing ratio $SR = \mathrm{n}.\rho / \mathrm{V}$
  - n is the revolution rate of the auger (rpm)
  - p is the pitch of the auger (meter p round)
  - V is the rate of penetration of the auger (m/min)

- Which target value should we take? 1? 3? More?
- Related to the installed power of the piling rig in a given soil.
- Related to diameter

Antwerp (Belgium)

CFA piles of large diameter-analysis of the SR

- 1200 mm and 1000 mm piles in dense sands (18.00 m)
- Rig with following characteristics:
  - Maximum torque : limited to 300 kN.m
  - Maximum rotation speed 20 T/m
  - Pull-down capacity : 15 T.
- SR-values of 5 to 8 were observed.
- SLT were performed showing
  - No direct relationship with SR ratios
  - A behaviour close to the one of a bored pile



Construction CFA (Augercast)

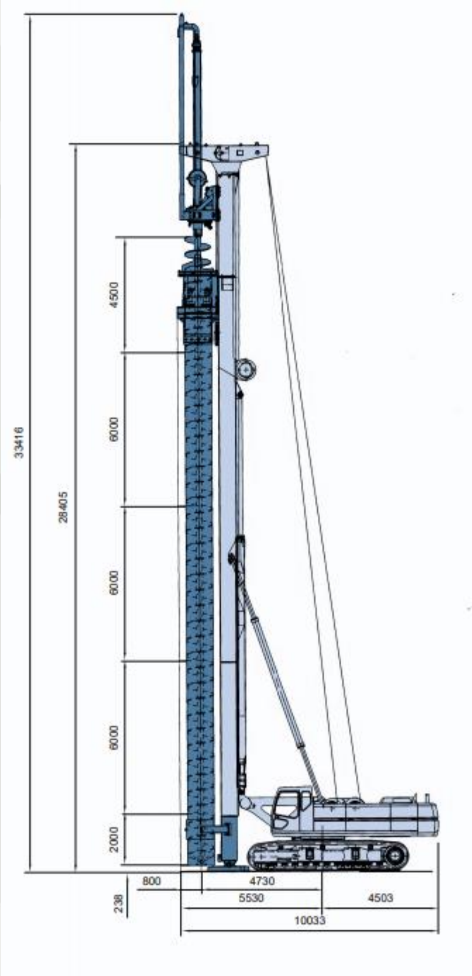
Systems with larger stem

- High torques up to 30 Tm/pull down up to 20 T
- Diameters up to 800 mm (32 inches)
- Long piles : more than 30 m (100 feet)
- Several ratios stem/auger
- Reinforcement before concreting

Construction CFA (Augercast)

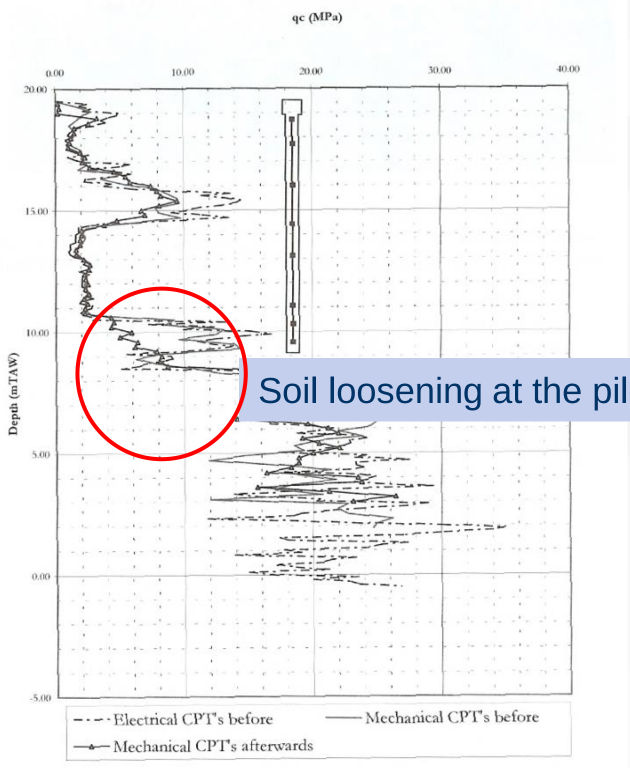
Cased CFA – FOW – CSP

- 300 mm (12 inches) to 800/900 mm (36 inches),
- length 20.00 m (700 feet)
- rigs twin RD 10 to 15 Tm max. (75.000 to 110.000 lbf ft)
- limited crowd



Construction CFA (Augercast)

Cased CFA – FOW – CSP



Soil loosening at the pile tip

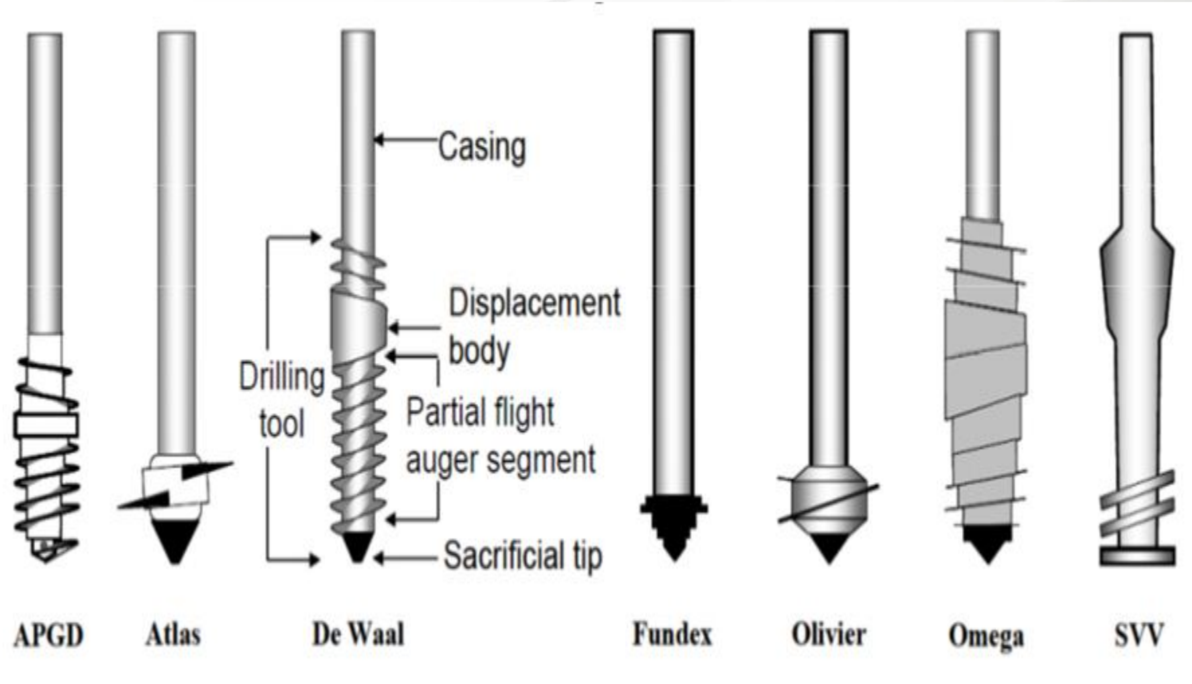
- Bustamante (2001) : This system promises
  - Less disturbance (loosening) of the surrounding soil, especially in sandy soils
  - Limitation of the over-volume of concrete.

But :

- Equipment influence: low installed power
- No beneficial influence of high penetration rate and concreting phase
- Full-scale load-tests (Theys, 2002): soil relaxation at pile basis.

Displacement screw piles

A large variety of systems

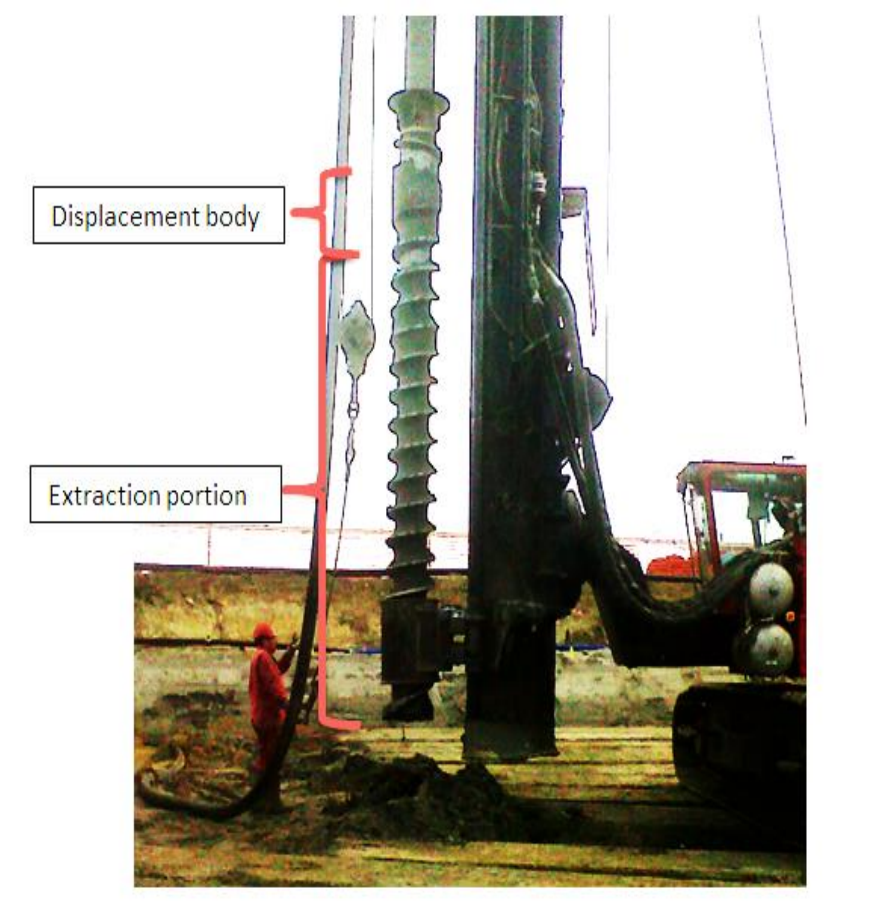


- Shape of the auger – movement of the spoil
- Shape of the auger – effect on end bearing
- Shape of the auger – shape of the final pile
- Power of the piling rig to Rotate
- Power of the piling rig to Push – force auger penetration
- Casting method (pressure) of the concrete placement
- Control of auger extraction – effect on the shape of the final pile

Displacement screw piles

A large variety of systems

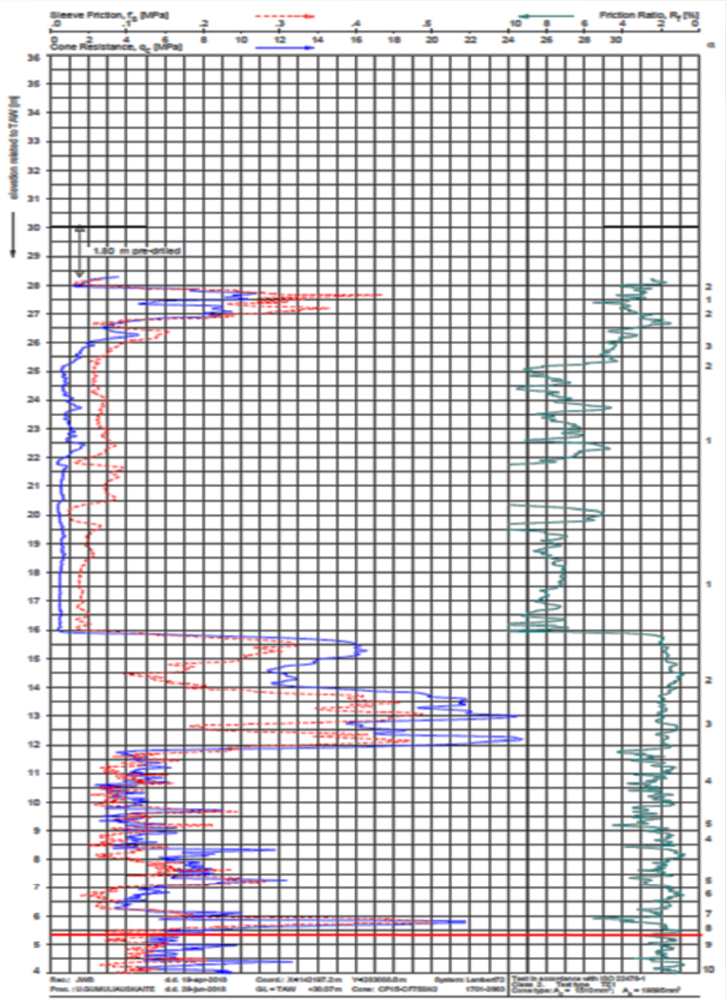
- Emergence of new systems with variable lengths of extraction portion
- Systems evolve towards larger diameters (recently 850 mm in the NL)
- Grout-injected systems are gaining in popularity
- Load-tests are required in order to assess real impact of each specific system



Displacement screw piles

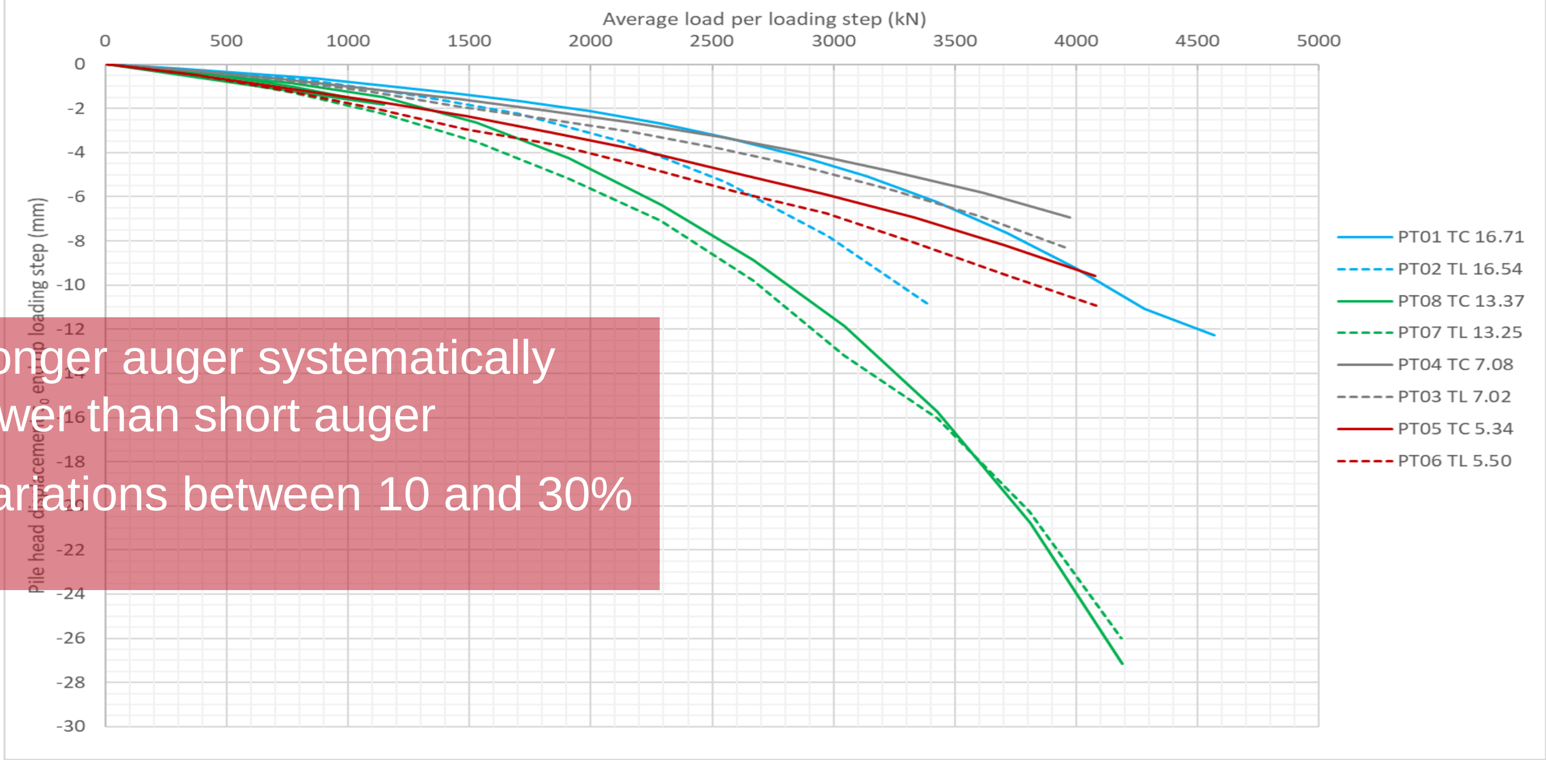
Load test in variable soil conditions/impact of the extraction portion

- Omega screw piles 610 mm installed in pairs:
  - One with a “classical” extraction portion 0.95 m
  - One with an extended extraction portion 1.80 m
- Piles installed in sand and chalk.
- Fully instrumented load tests
- Load distribution was deduced from the fibre optic sensors



Displacement screw piles

Load test in variable soil conditions/impact of the extraction portion



- Longer auger systematically lower than short auger
- Variations between 10 and 30%

2

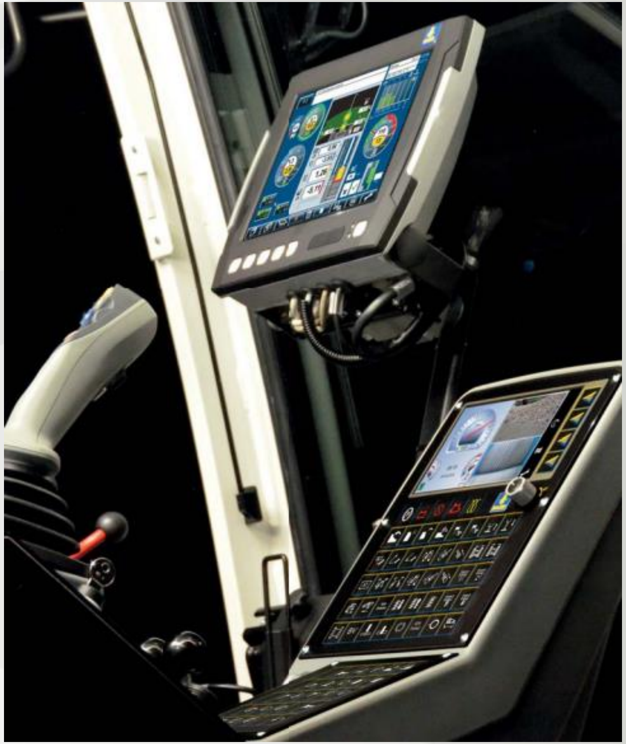
ADVANCES IN TESTING AND MONITORING

Real time data and more accurate information

Advances in monitoring/Digitalization

Real time data/Enhanced accuracy

- GPS positioning
  - Very useful for large sites
  - Enables to keep correct records and documentation
- Production record and monitoring
  - Better documentation of site
  - QA/QC tool guaranteeing repeatability and reliability of pile construction
  - Advanced identification of production problems
  - Timely reaction on site
- Automated assistance of pile installation
  - Automatic uplift of auger piles
  - Drilling assistant to limit over-augering
  - Drilling simulator for new trainees



Advances in monitoring

Real time data/Enhanced accuracy

Monitoring is a relatively effective and reliable tool provided the presented records (e.g. Bustamante (2003):

- Come above all from rough data and give the adequate information (correct parameter)
- The sensor selected to measure each respective parameter has the capability to do it
- Is examined globally taking into account
  - the real soil conditions (and possible variations),
  - the rig characteristics,
  - the many possible incidents

Pile Drilling Report
Paal Data Registratie
Enregistrement de Pieu

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Bouwput info:

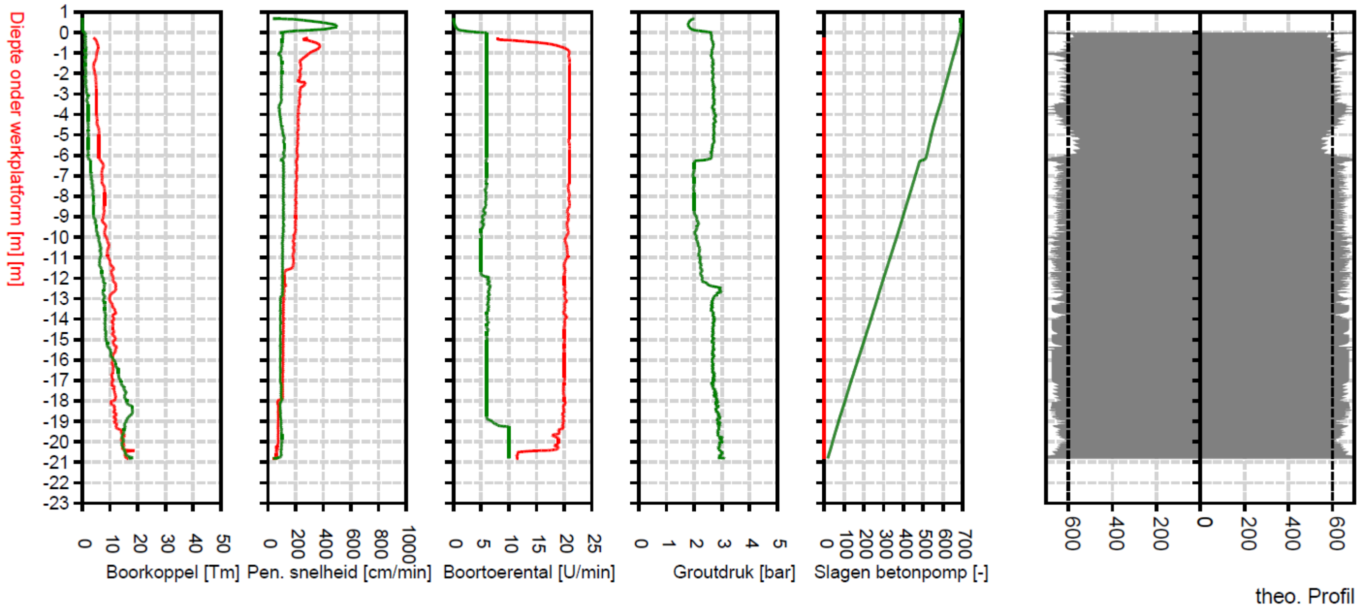
Naam bouwput:	1170411 (YBUY- BMAR)
Plaats:	BEVEREN
Opdrachtgever:	Oil Tanking AGT
Aannemer:	AB EIFFAGE
Machine:	F3500_04

Gegevens van paalnr: 56

Datum:	20/02/2018	Werkpeil:	0,00 m
Starttijd:	8:11:36	Paallengte:	20,82 m
Eindtijd:	8:53:08	Paaldiameter:	1200 mm
Tijdsuur:	00:41:32	Betonvolume:	29,63 m³
Pauze:	00:00:00		

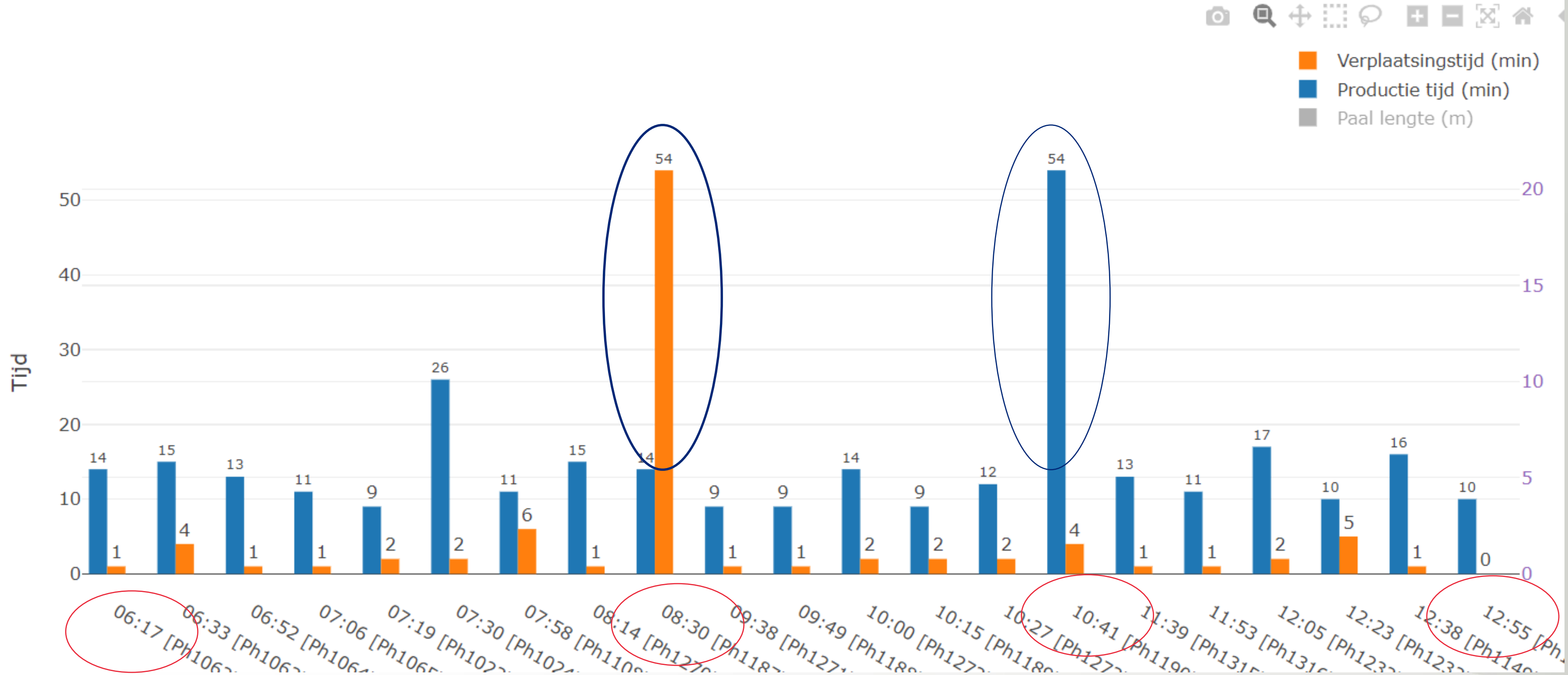
Time diagram / Tijddiagram / Diagramme de temps

Depth diagram / Dieptediagram / Diagramme de profondeur



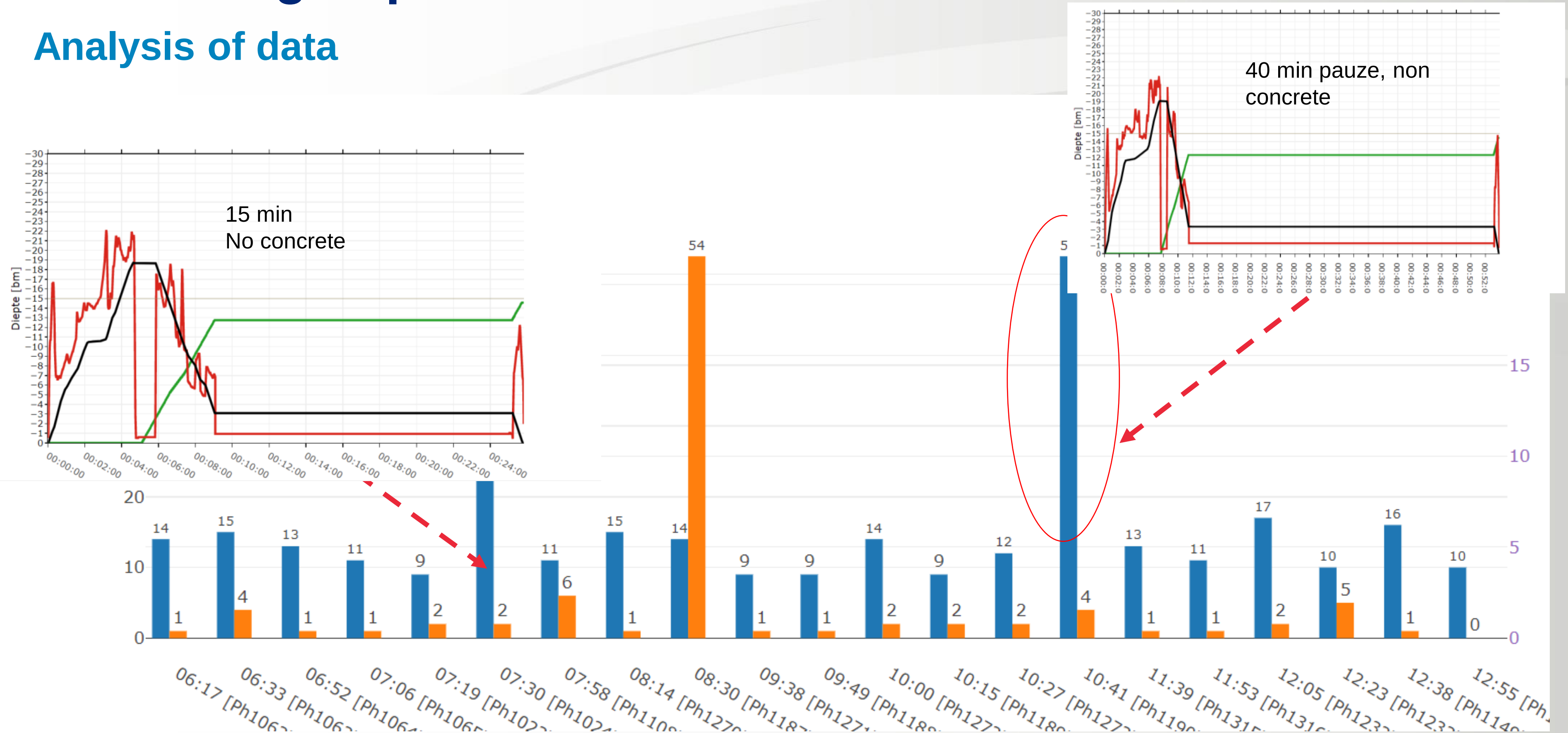
Monitoring of pile execution

Accurate records



Monitoring of pile execution

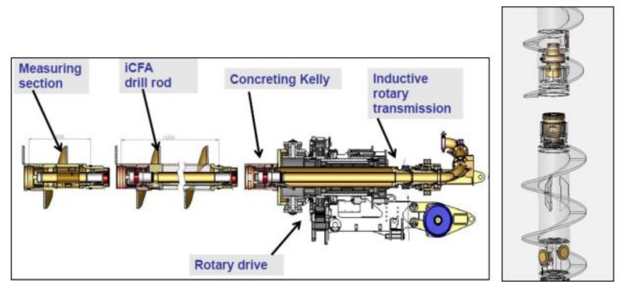
Analysis of data



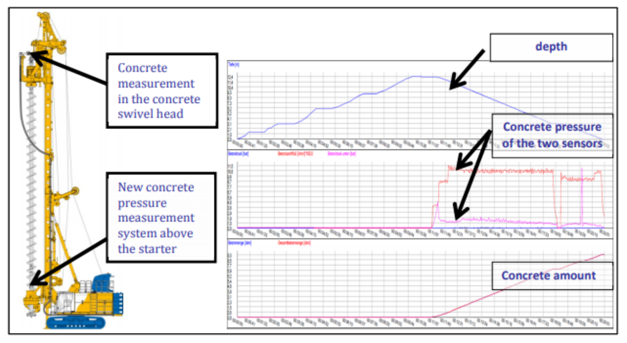
Augercast Piles

New developments in monitoring

- Drilling and control of over-augering : modern monitoring systems can help the operator to control the screwing ratio in real time (so-called drilling assistant)



- Concrete and control of pressure : new systems are developed in order to measure the concrete pressure at the bottom of the auger and transmit the information through the auger.



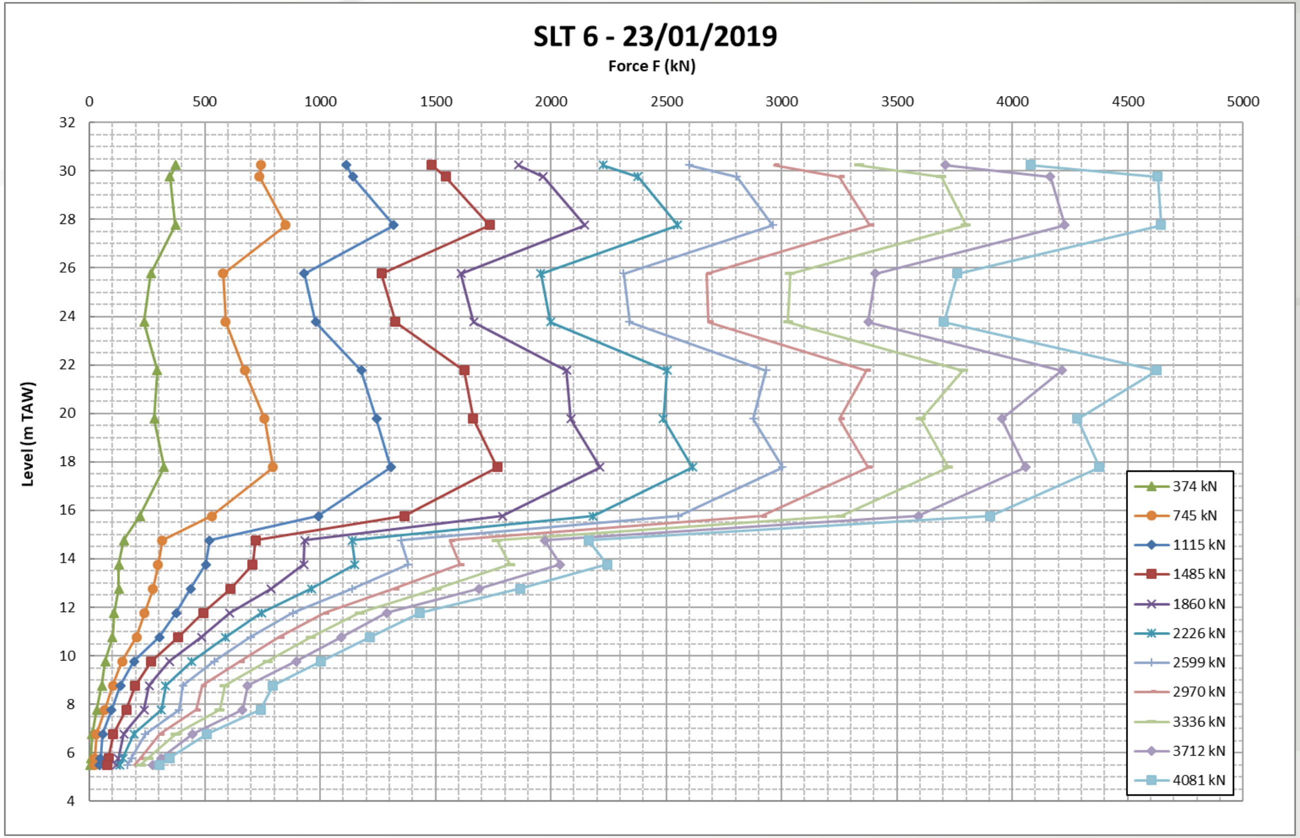
Advances in testing

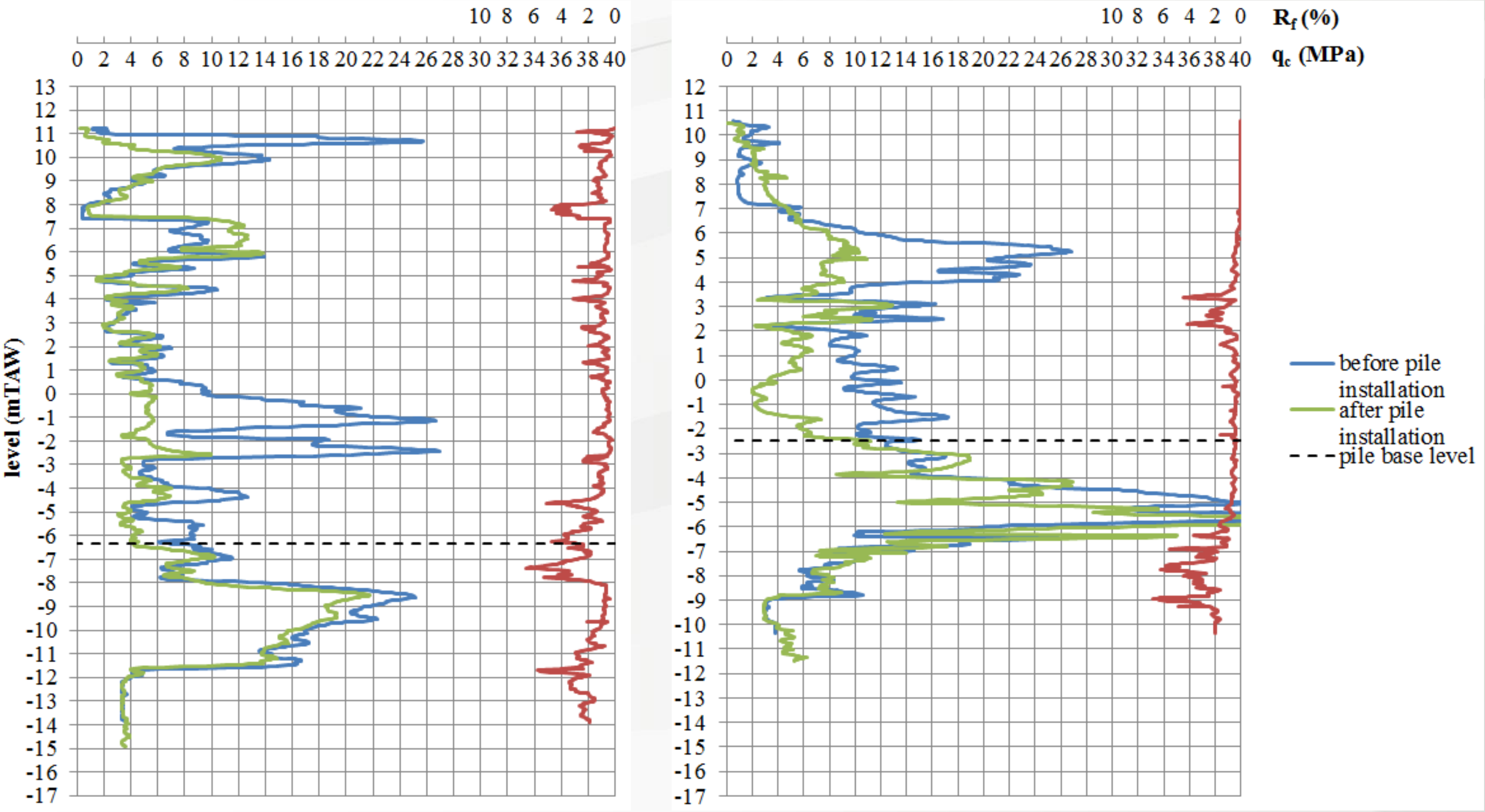
25 years of evolution

- Major advances in the ITC sector have found their way to the geotechnical sector:
  - Miniaturization
  - integrated electronics
  - wireless data transmission,
  - real time and online visualization,
- The most important advancement is the fibre-optics technology.

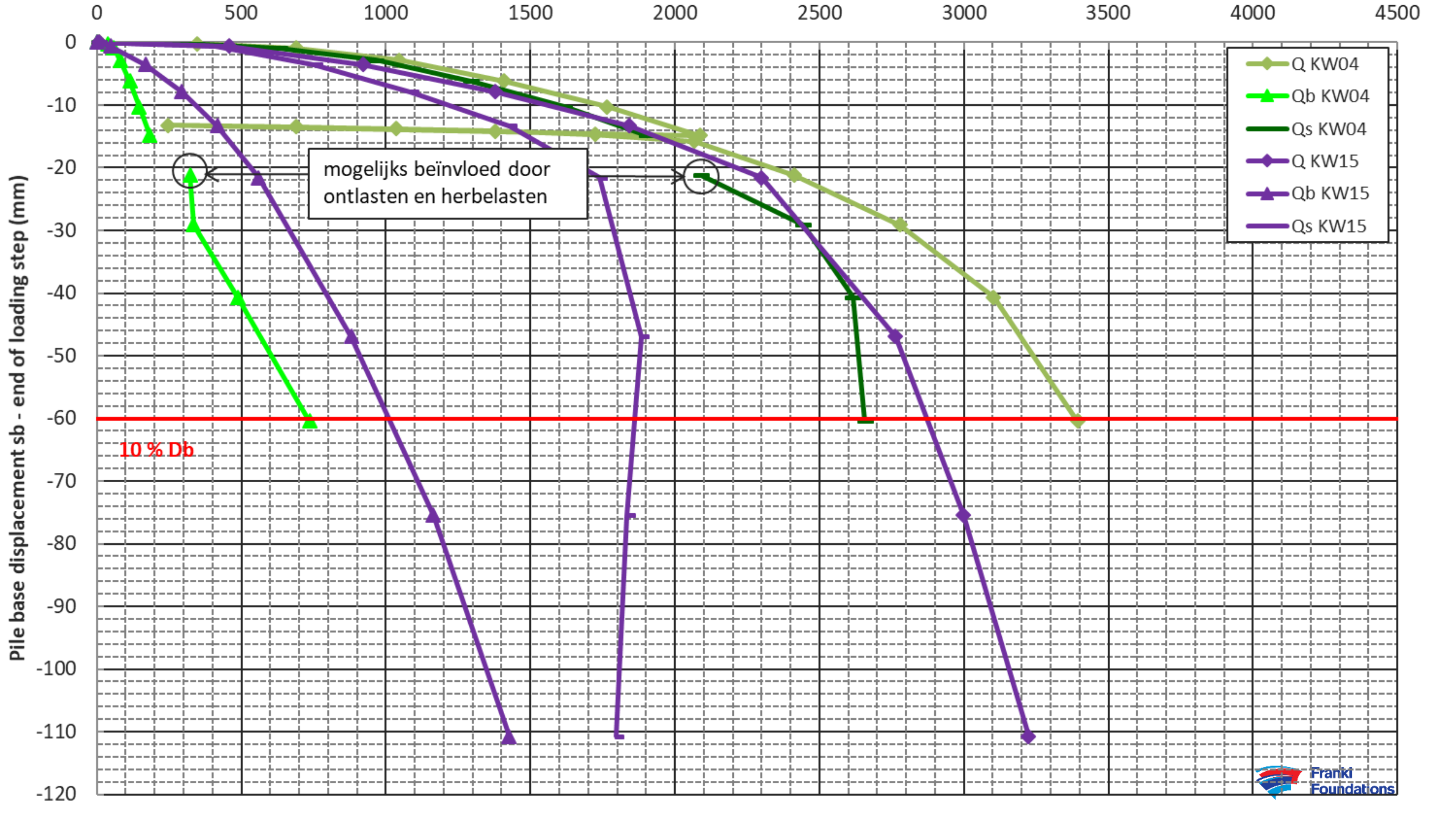
Displacement screw piles

Example of load test





Recent experiences with static pile load testing on real job sites – Verstraelen et al – Leuven 2016


0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
Pile base displacement sb - end of loading step (mm)
Q KW04
Qb KW04
Qs KW04
Q KW15
Qb KW15
Qs KW15
mogelijks beïnvloed door ontlasten en herbelasten
10 % Db
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CODES AND PILE DESIGN

CFA and Displacement Ac pile design

CODES AND EVOLUTION OF DESIGN PRACTICE

Peter Day (2017)

- Codes are supposed to
  - Establish the norms of the profession, and provide protection against legal action based on negligence,
  - Represent a distillation of existing knowledge on which there is consensus,
  - Should ensure fair competition.

- The practice of geotechnical engineering is a skill rather than a science. It involves perception and judgement, both of which are difficult to encapsulate in a code

Two comparison examples

Symposium by the **ERTC3** Piles in Leuven

Comparison exercise organised in **Bolivia** by Bengt Fellenius and Mario Terceros

Symposium by the ETC3 in Leuven (2016)

Trevor Orr (2016)

Example 3 :

- Design of 6 piles for a stiff building in North of France
- Types of piles:
  - 520 mm – 12,00 m long
- The soil consists of 0.8 m of unspecified material over 2,4 m quaternary silty sands over 5,4 m of dense quaternary sand over a deep deposit very dense sands.
- The ground investigation involved 1 CPT, 1pressuremeter (PMT) test and 1 boring with undisturbed soil sampling and laboratory tests.
- Eleven solutions were transmitted.

Symposium by the ETC3 in Leuven

Trevor Orr (2016)

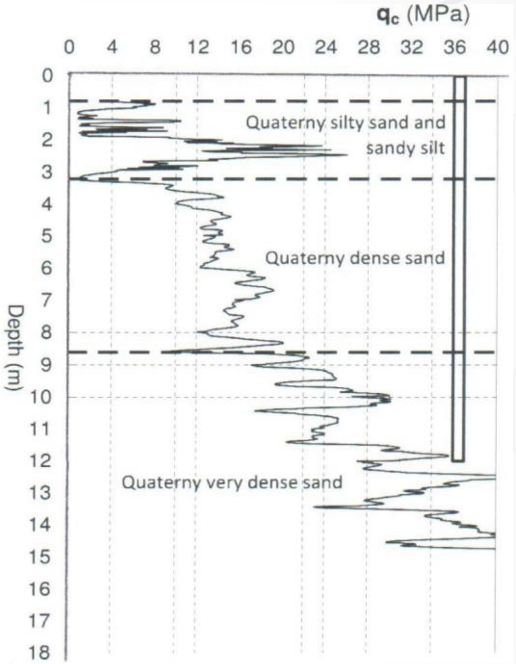
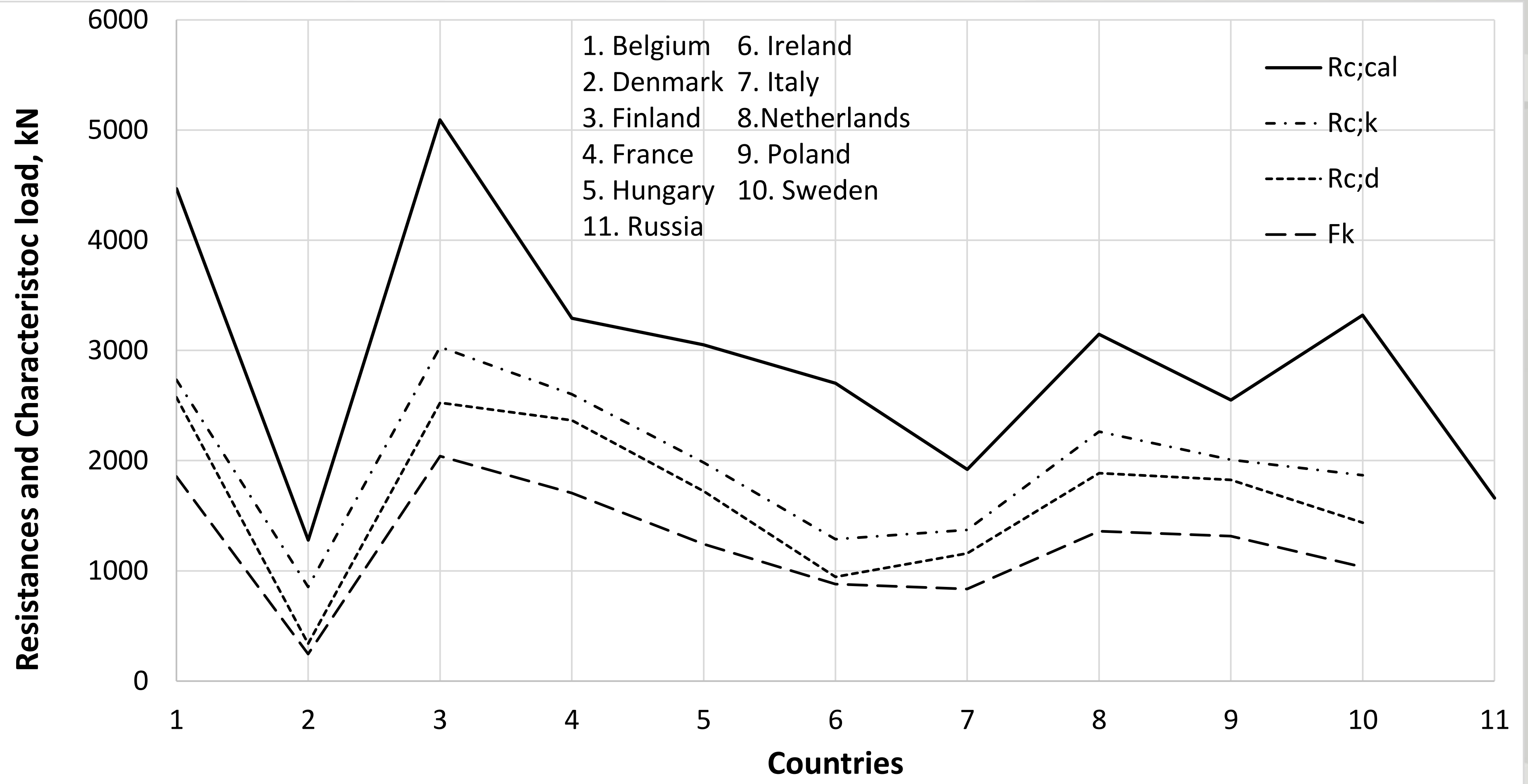


Table 8: Example 3: Soil properties

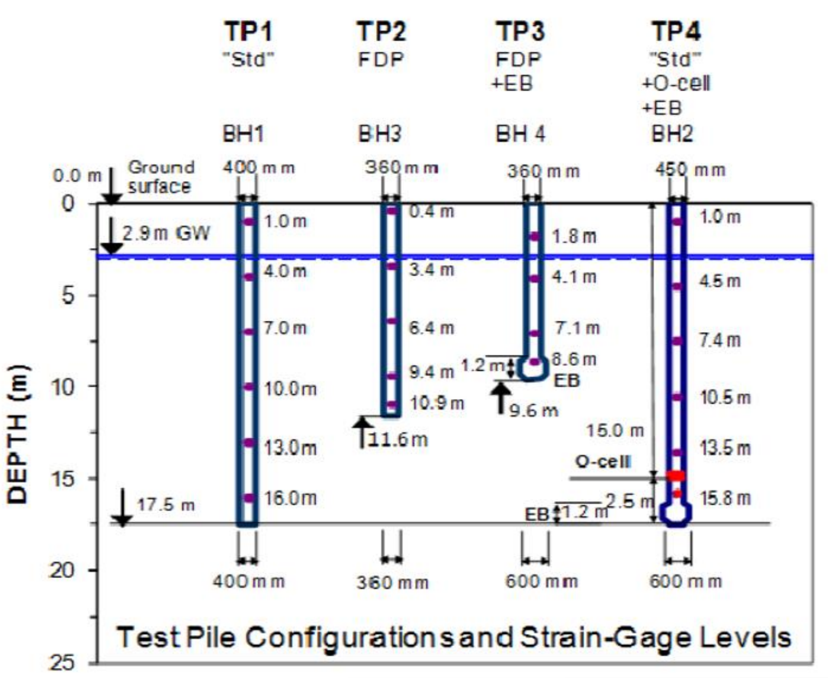
Depth (m)	phi (°)	c (kPa)	w (%)	γ_b (kN/m³)	γ_d (kN/m³)
5.45	30.2	0	18.5	19.2	16.2
6.85	31.4	4	24.8	19.09	15.3
7.45	31.1	0	18.3	19.03	16.08
8.65	30.2	6	21	19.87	16.42
9	31.6	0	19.1		
10.3	31.7	4	21.2	18.56	15.31
11	30.2	2	22.2	18.6	15.22
12.85	32.1	5	20.7	19.22	15.93
14.6	30.2	5	20.3	19.31	16.05



6000
5000
4000
3000
2000
1000
0
Resistances and Characteristoc load, kN
1. Belgium
2. Denmark
3. Finland
4. France
5. Hungary
11. Russia
6. Ireland
7. Italy
8.Netherlands
9. Poland
10. Sweden
Rc;cal
Rc;k
Rc;d
Fk
1
2
3
4
5
6
7
8
9
10
11
Countries

Comparison exercise in Bolivia

Bengt Fellenius et al



The test piles were bored and screw piles described as follows:

TP1: a nominally 400 mm diameter pile, 17.5 m long, bored under bentonite ("standard pile").

TP2: a nominally 360 mm diameter pile, 11.6 m long, FDP (Full Displacement Pile).

TP3: a nominally 360 mm diameter pile, 9.6 m long, FDP (Full Displacement Pile) and with a 600 mm diameter Expander Body, placed at the pile toe.

TP4: a nominally 450 mm diameter pile, 17.5 m long, bored under bentonite and with a 600 mm diameter Expander Body, EB, placed at the pile toe and with an Osterberg cell above the EB.

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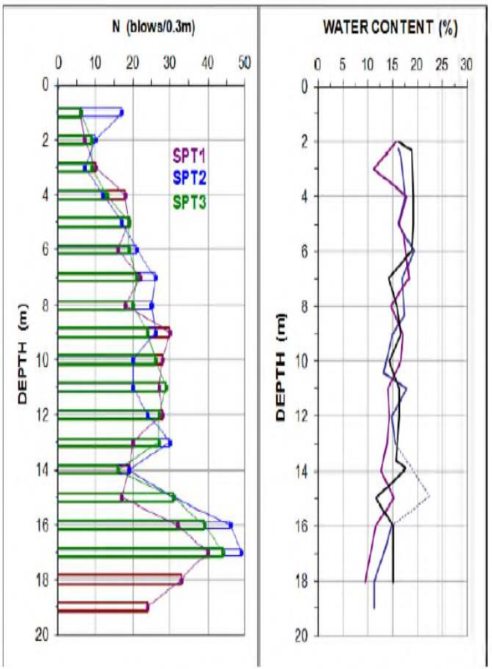
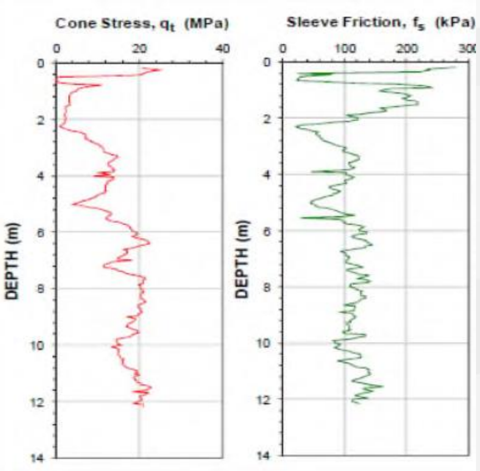
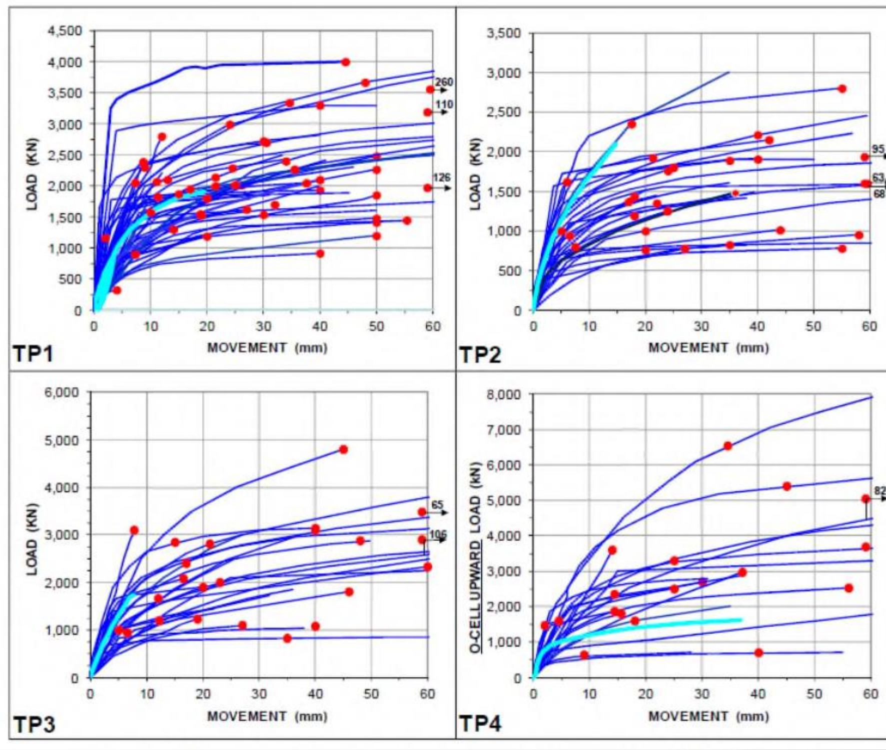
Comparison exercise in Bolivia

Bengt Fellenius et al





A total of 50 predictions were received from 63 individuals in 19 countries and all continents.
Only one was Bolivian.



CODES AND EVOLUTION OF DESIGN PRACTICE

First conclusions

- The theoretical pile capacity can differ in function of
  - the code itself
  - the calculation method
  - the local experience/knowledge
  - the skill of the designer
- But the installed pile capacity can largely vary as well because of the different aspects governing the pile installation:
  - system details,
  - equipment capacity,
  - monitoring during and after pile installation

CODES AND EVOLUTION OF DESIGN PRACTICE

Augercast and DD piles design

- Bearing capacity is specifically assessed for CFA piles in most codes through:
  - Specific installation factors (effect of the installation)
  - Specific model factor (uncertainty of the prediction of the pile performance)
  - Specific partial safety factors (uncertainty of the pile execution)
  - Typical allowable values using a global factor of safety of 3 to 5 (including other indirect installation or correlation factors)
- DD piles are not necessarily specifically covered
  - Yes in Be, Fr, Nl, Ge
  - Not in I, Sp, UK
  - Typical allowable values using a global factor of safety of 2 to 3 (including other indirect installation or correlation factors)

CAN WE ALIGN CODES AND RECENT TECHNOLOGICAL ADVANCES?

The Belgian example

Aligning technological developments and design codes

Lessons learned (I)

- More load testing is needed to calibrate installation factors,
- Economic incentives that favour QC monitoring and testing should be introduced in codes and standards,
- Standards and codes should leave the door open and even stimulate innovative techniques and processes,
- In the context of design it is important to have a relation between the risk class of a geotechnical structure and the safety factors.

Aligning technological developments and design codes

Lessons learned (II)

- Execution systems are in constant evolution, and small details can result in major differences. The codes are usually not enough up to date to take these new evolutions into account.
- All installation methods may prove to be inadequate in function of the local soil conditions, or the installed equipment capacity.
- The response of some types of soils to the solicitation of pile installation procedure, can be dramatically different than expected. This is specifically the case in intermediate soil types or in rapidly changing soil conditions.
- Structural aspects and the impact of materials should not be underestimated.

Installation coefficients need to be related to the "real" set of parameters of the specific jobsite.

Aligning technological developments and design codes

How to proceed?

- Better knowledge of the pile behaviour through instrumented Load Testing
- Better follow-up of local discrepancies through best use of modern monitoring:
  - Real-time access to all site and equipment related data
  - Detailed report with selection of specific data for further analysis and quality documentation
  - Focused follow-up by in-house expert team.
- How to account for this in codes:
  - Installation factors aligned on demonstrated performance
  - model and safety factors
    - aligned on proven reliability
    - Rewarding in-situ testing.

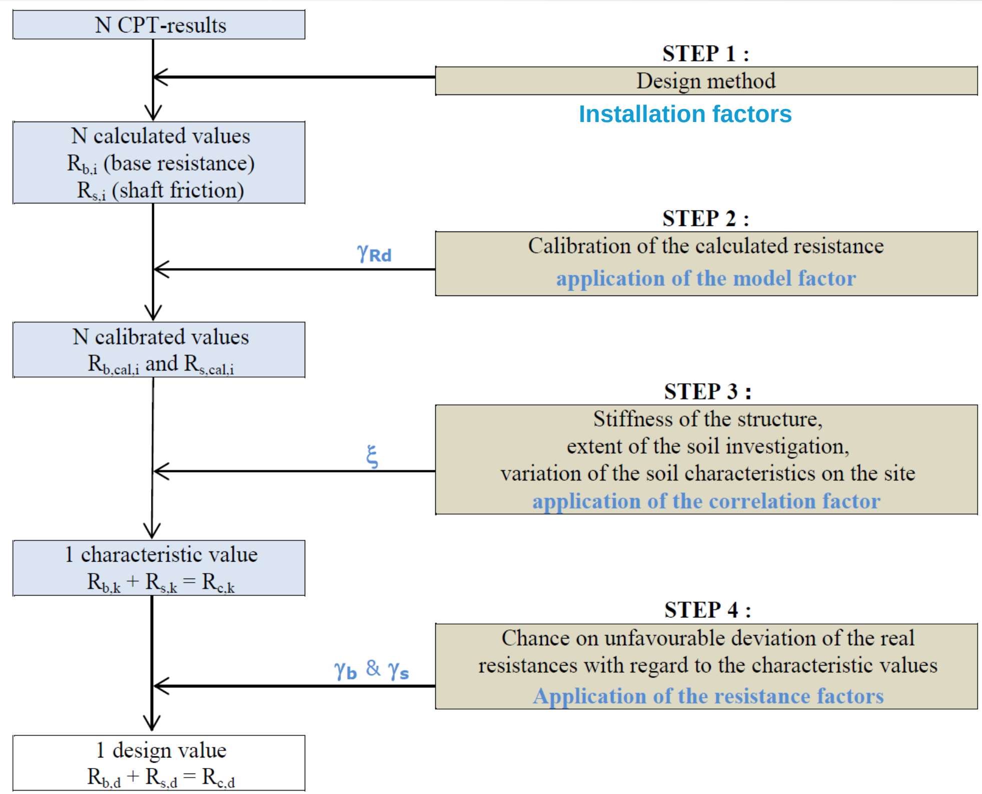
Aligning technological developments and design codes

The Belgian proposal

- Belgian national annex of the EC 7
- "GEO"-verification according to Eurocode 7:

$$F_{c,d} \leq R_{c,d}$$

- Schematic overview of the different steps to calculate the design value of the compressive resistance of the pile $R_{c,d}$.



Aligning technological developments and design codes

The Belgian proposal

- The following principles have been provided in the Belgian design methodology as described in WTCB-CSTC, (2009/2016):
  - Installation factors α_b and α_s, are function of pile (sub) category. These generic installation factors are rather conservative, but the document provides a **methodology** (instrumented pile testing program in different soil types) and acceptance criteria **to get better installation factors for individual pile systems**.
  - Model factors γ_{rdi}, are function of the availability of instrumented SLT's.
  - Correlation factors $\xi_{3,4}$ are function of the intensity of the soil investigation tests.
  - Safety factors $\gamma_{b,s}$ are function of the quality of the QC provided for the production piles.
- System of Certified Technical Approvals launched by the Belgian certified agency BUtgb-UBAtc, granting for an individual piling system specific installation factors, as well as model factors and safety factors that account for a period of five years.

Conclusion

Is it possible to align Codes with Technological advances?

- Yes, if codes:
  - Take into account local knowledge and understanding of pile behaviour
  - Are evolutionary instruments which align quickly on new developments
  - Make the best use of new technologies in order to:
    - Give adequate insight on pile behaviour through testing
    - Monitor pile performance in the field
  - Reward the correct understanding and monitoring of pile execution and the related increase in reliability by adapted installation, model and safety factors
- The Belgian proposal goes in this direction with a system of Certified Technical Approval for pile systems complementary to the Belgian NA of EC7.


Thank You
ir Maurice BOTTIAU
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