Bi-Directional Pile Load Testing

Dr. Melvin England, Maarten Profittlich MSc.

Seminar Pile Load Testing, 21 October 2021, Den Haag (NL)

Overview Presentation

- Introduction and history
- Optimisation foundation design
- Principles of bi-directional pile load testing
- Analysis of the results and application of (Dutch) Codes
- Applications and Project Examples
- Summary, conclusions and call to action!

Introduction (1)

Mission

"REDUCING UNCERTAINTY AND CREATE VALUE WITH THE OSTERBERG CELL LOAD TEST"

The mission of Fugro Loadtest is to be the world's leading service provider in the collection and interpretation of data relating to foundation testing, in particular bi-directional static load testing with the Osterberg Cell (O-cell).

Introduction (2)

History

- LOADTEST Inc. started in 1991, Florida
- Operating around the world from 5 LOADTEST offices
- 60 staff – mostly engineers; some of our staff are recognised leading experts in various forms of pile testing
- €15 M yearly turnover (1/3 USA)
- Portable test systems allow easy access to very remote locations
- Structural and geotechnical instrumentation
- LOADTEST was integrated in the Fugro group in January 2009 and we can now operate from any of the Fugro offices around the world and call on the resources of Fugro where necessary
- 2014 Fugro Loadtest was integrated into the Fugro UK Land operation and from 2021 in the Fugro NL Land

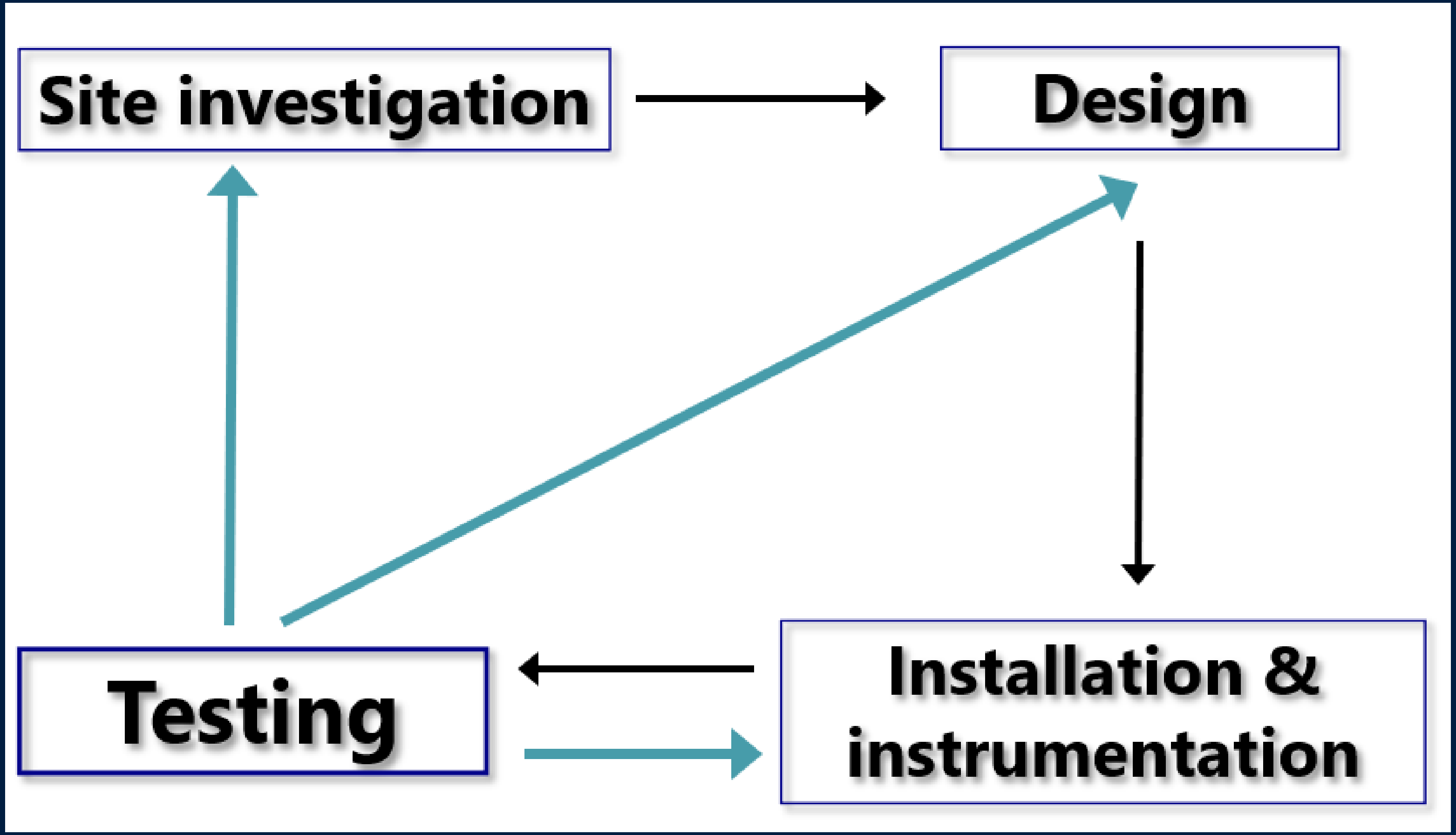
Introduction (3)

Osterberg Cell ®

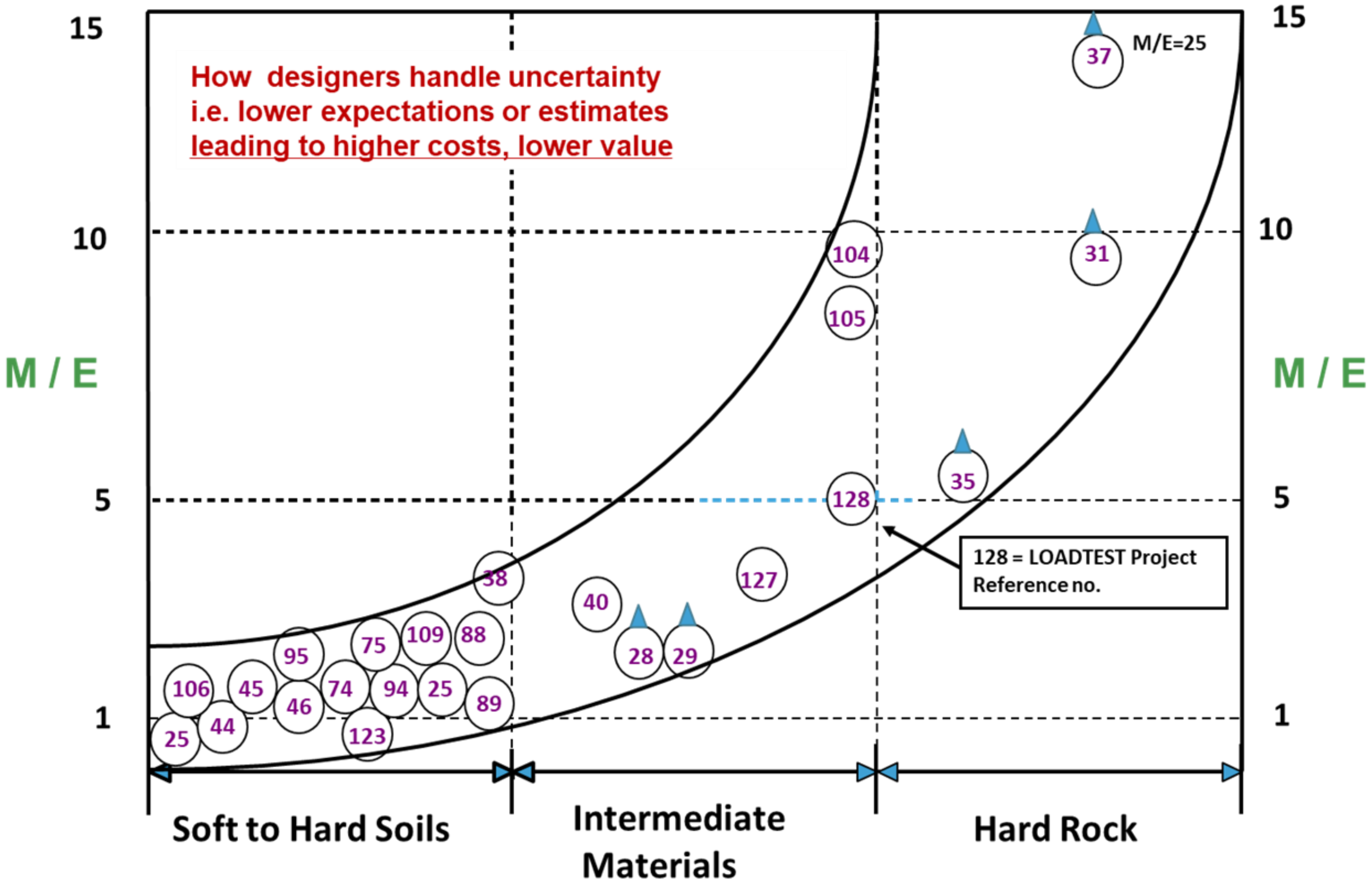
- Our most special and successful pile load testing is bi-directional load testing using the Osterberg Cell® (or **O-cell**)
- Invented by **Dr. Jorj O. Osterberg** (1915-2008), US Civil Engineer
- Testing method developed from 1985-1987, first commercial tests on bored piles in 1989
- **Patents** held by Fugro
- Purpose built hydraulically driven, high capacity, sacrificial **loading device**
- Installed **within** the foundation unit (pile, barrete)
- After pressurized, it begins working by loading in **2 directions**, upward against upper skin friction and downward against base resistance and lower skin friction (if applicable)
- **Fully compliant** with American/ European codes

Optimisation Foundation Design

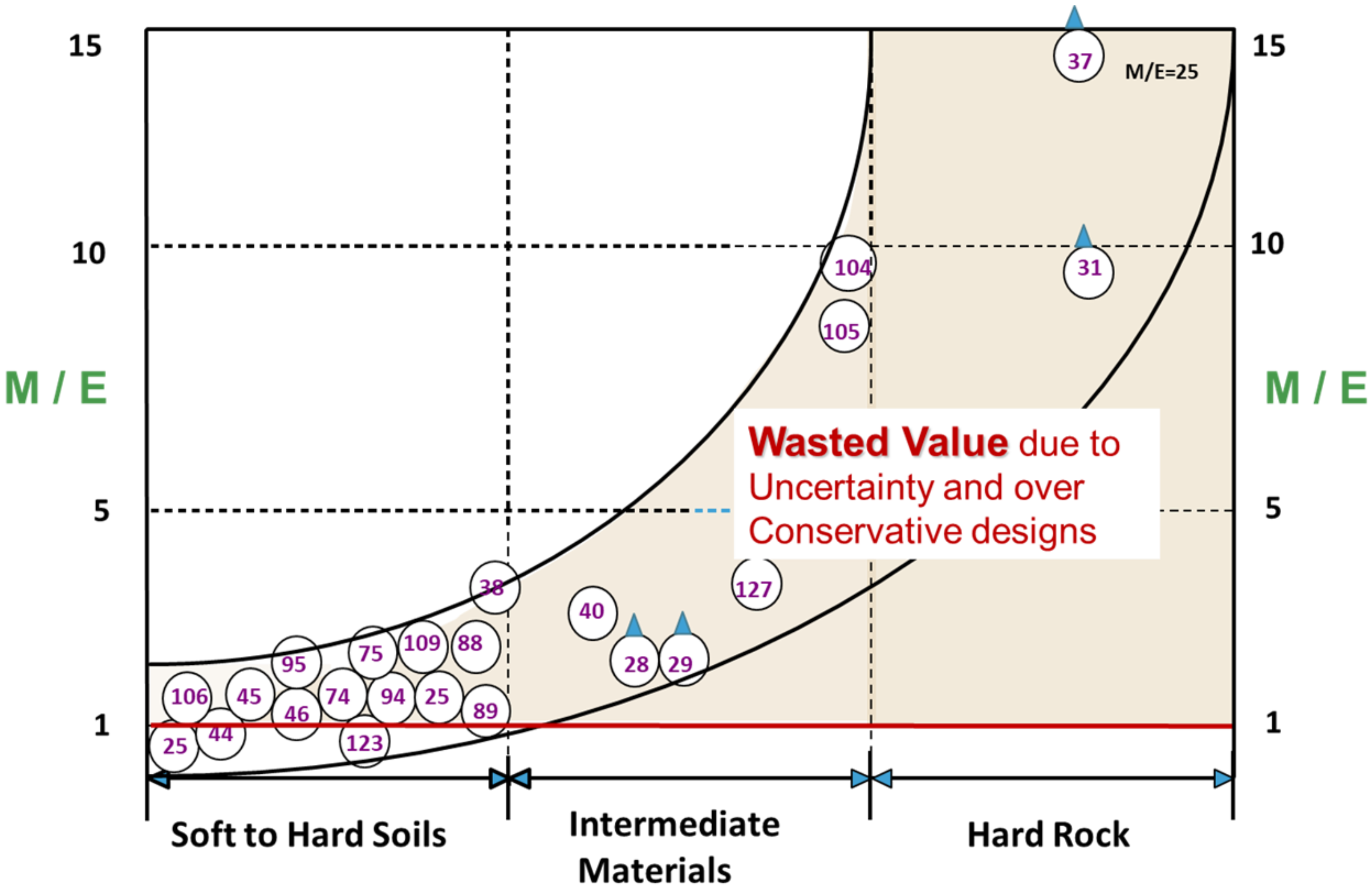
- Pile load testing is part of the optimisation foundation design, together with site investigation
- It is about a safe and economical pile foundation design, according the applicable codes and guidelines
- And to avoid overdesigned foundations and save money*



Ratio of Measured (M) to Esitmated (E) Bearing Capacity (1)



Ratio of Measured (M) to Esitmated (E) Bearing Capacity (2)



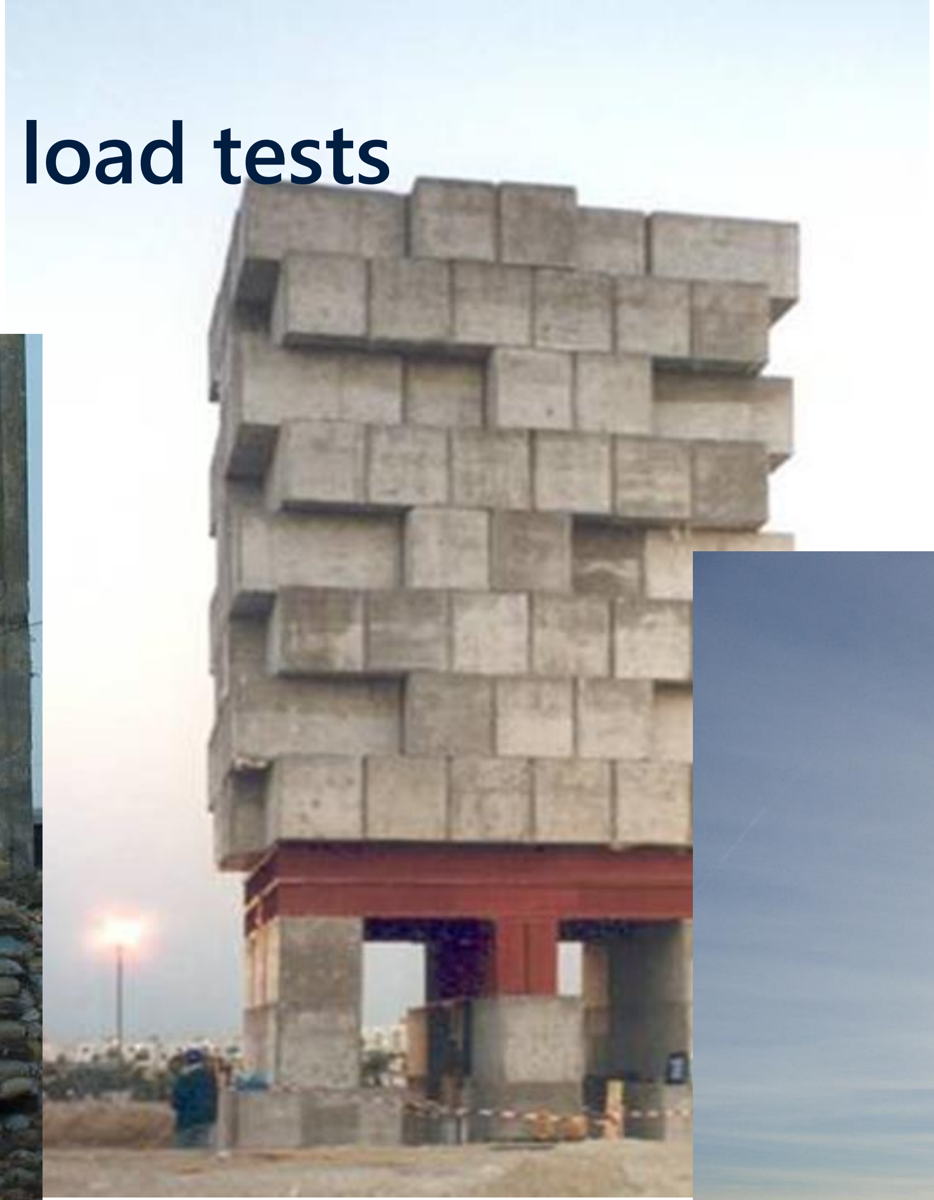
Case histories (1)

Foundation Savings After Testing Based On Actual Jobs Completed								
Job Number	566	775	835	381	056*	335	426	635
State	CA	FL	NC	NJ	SC	GA	TX	FL
Foundation Cost Estimate	$850,000	$6,200,000	$32,500,000	$18,000,000	$160,000,000	$3,276,000	$8,500,000	$4,520,000
Foundation After Test	$610,000	$4,980,000	$24,500,000	$8,900,000	$125,000,000	$3,003,000	$8,500,000	$7,232,000
Savings	$240,000	$1,220,000	$8,000,000	$9,100,000	$35,000,000	$273,000	$0	-$2,712,000
Test Cost	$79,000	$365,000	$2,000,000	$255,000	$7,500,000	$240,000	$95,000	$305,000
NetSavings	$161,000	$855,000	$6,000,000	$8,845,000	$27,500,000	$33,000	-$95,000	-$3,017,000
Calculated Factor of Safety	2.5	3.0	3.0	3.0	3.0	3.0	3.0	2.5
Measured Factor of Safety	3.0	3.5	4.0	5.0	NA	3.5	9.5	0.8
Factor of Safety After Redesign	2.0	2.0	2.0	2.0	2.0	2.3	9.5	2.0

Case histories (2)

- We have seen sizable project savings as a result of load testing, routinely.
- About 70% of the testing we have done saved the client money.
- Of most of the remaining 30%, more than half didn't realize the savings because the testing was done too late in the project or test data not used.
- With the rest, the savings was incalculably high and in the future (liability and remediation) after showing the foundation design was overestimated.
- In only a few cases the engineers' estimates were very close to the measured ultimate but often savings still result as a higher factor can be used.

Traditional static load tests



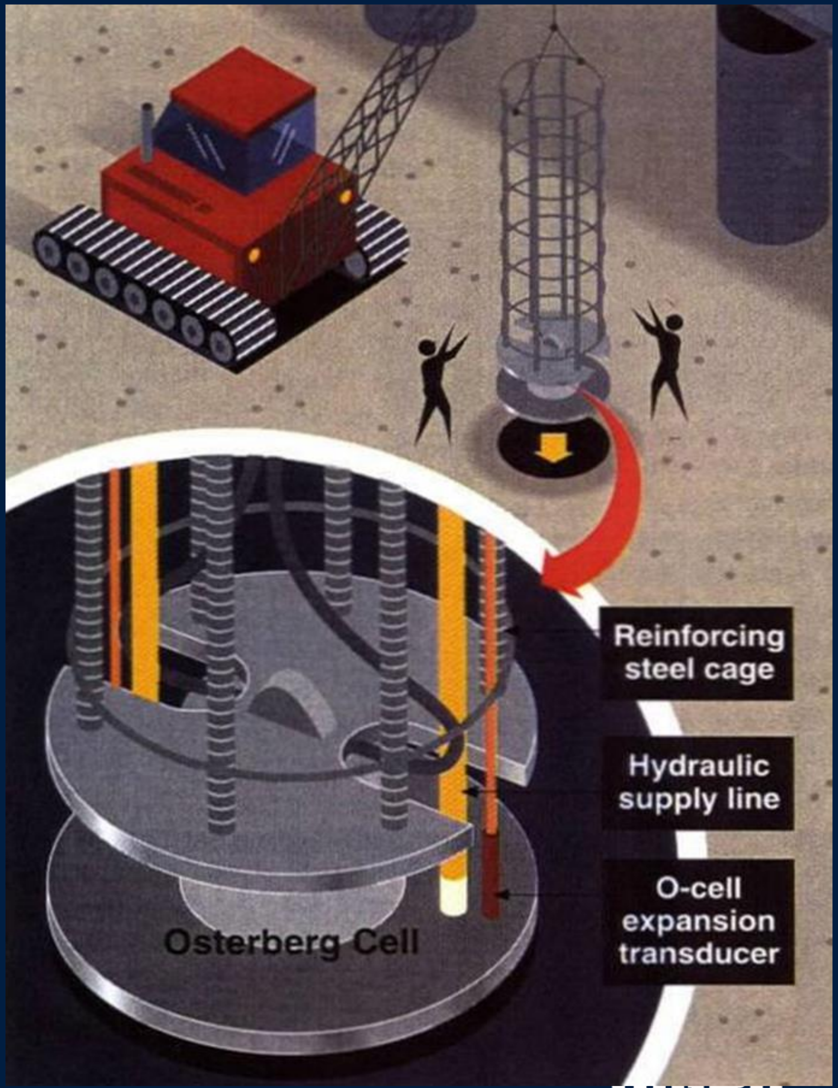
Risks of traditional static load tests

Due to platform/ground failure

Due to tension bar failure

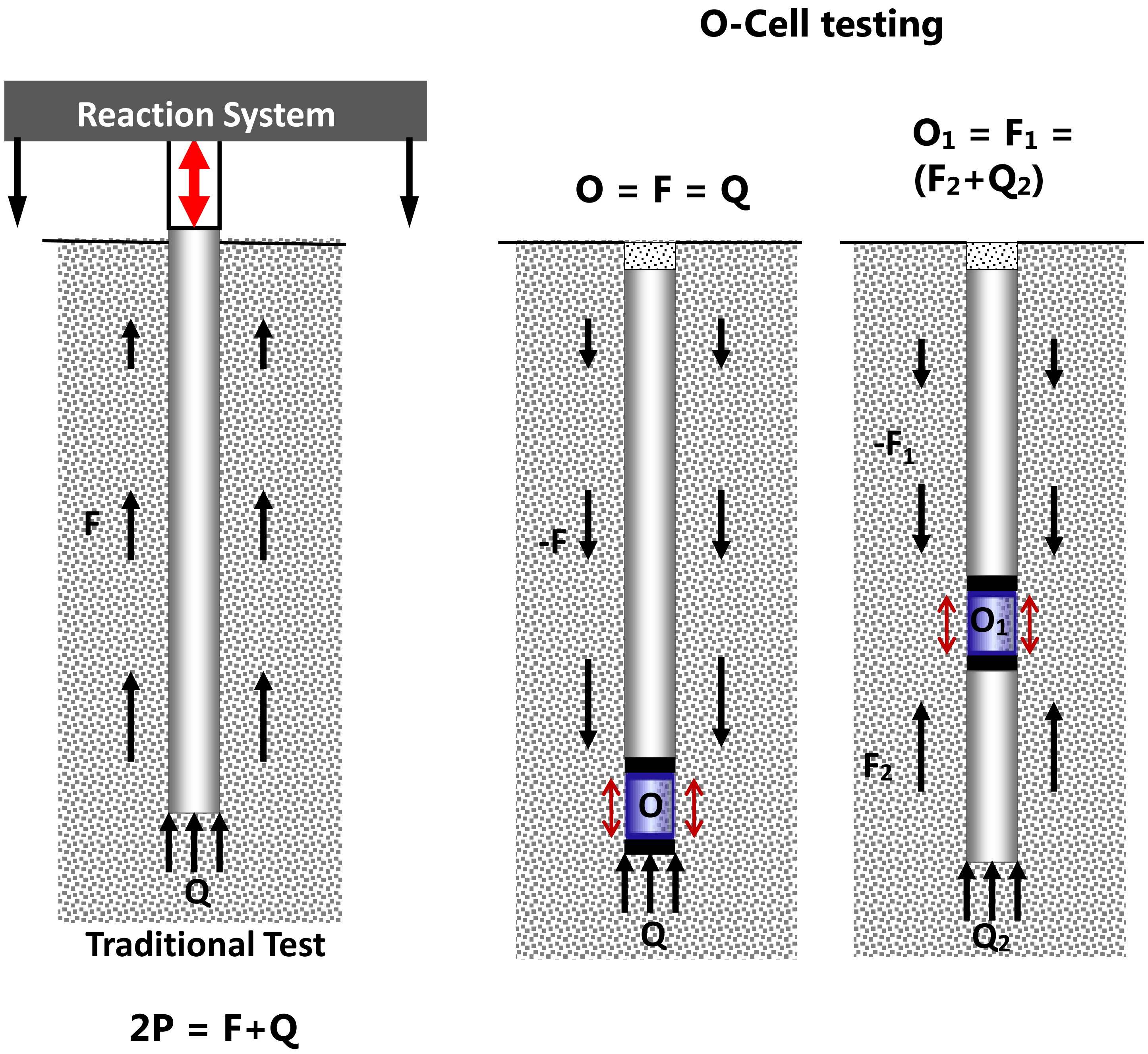
Principles of bi-directional pile load testing

- Based of the use of the application of a purpose built hydraulically driven, high capacity, sacrificial loading device, which begin to work by loading in 2 directions after pressurisation of the system
- Installed within the foundation unit (pile, barrete), close to the toe of the unit
- The O-cell uses all reaction from the soil and/ or rock system and the foundation element itself
- No restrictions by the limits of overhead and tie-down piles
- Specially instrumented to allow direct measurements of the O-cell's expansion with displacement transducers and strains with strain gauges
- Range in capacity from appr. 1 to 27 MN, and more with the use of multiple O-cells (and /or multiple levels)

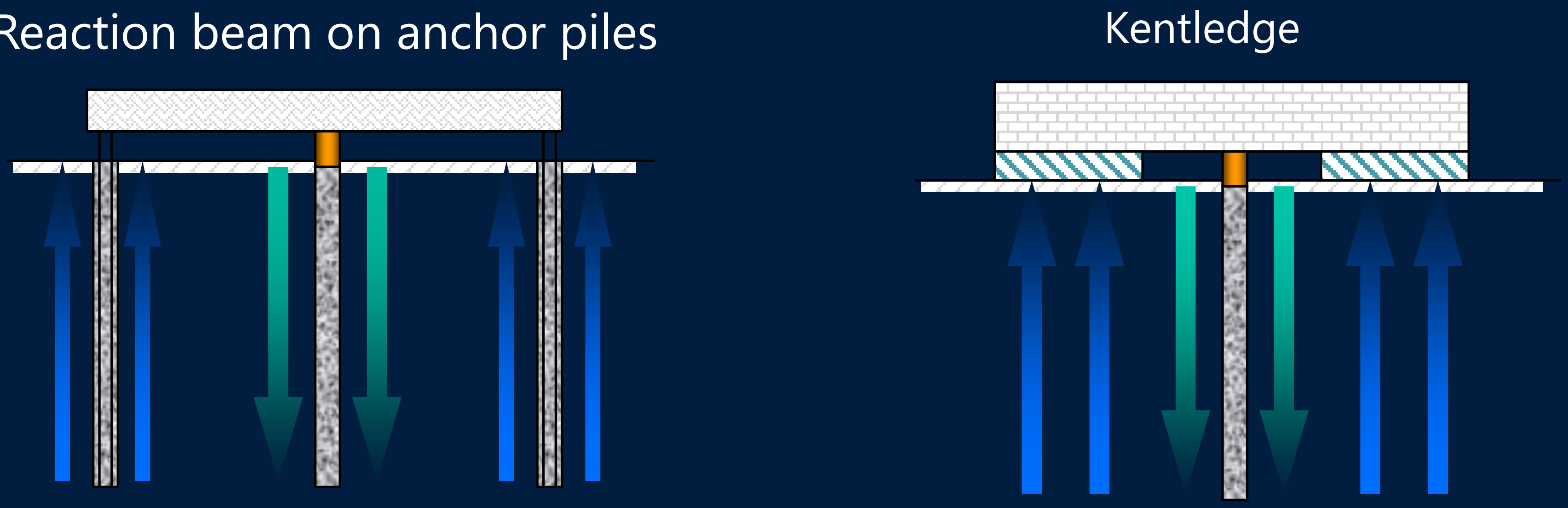


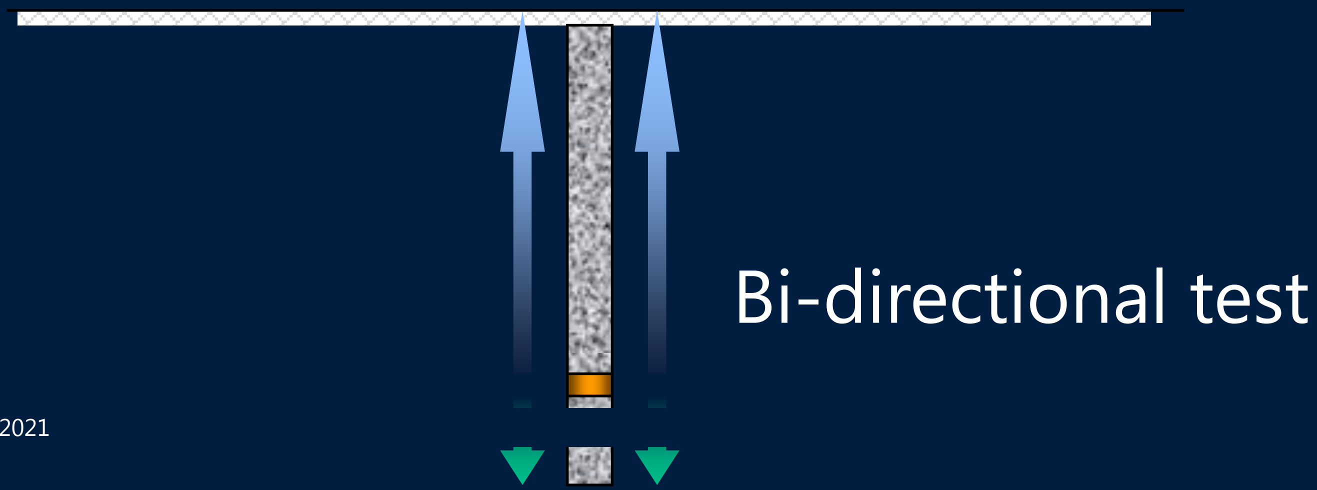
Comparison of O-cell and Traditional Tests

F = shaft friction
Q = end bearing



Zone of influence of static load test

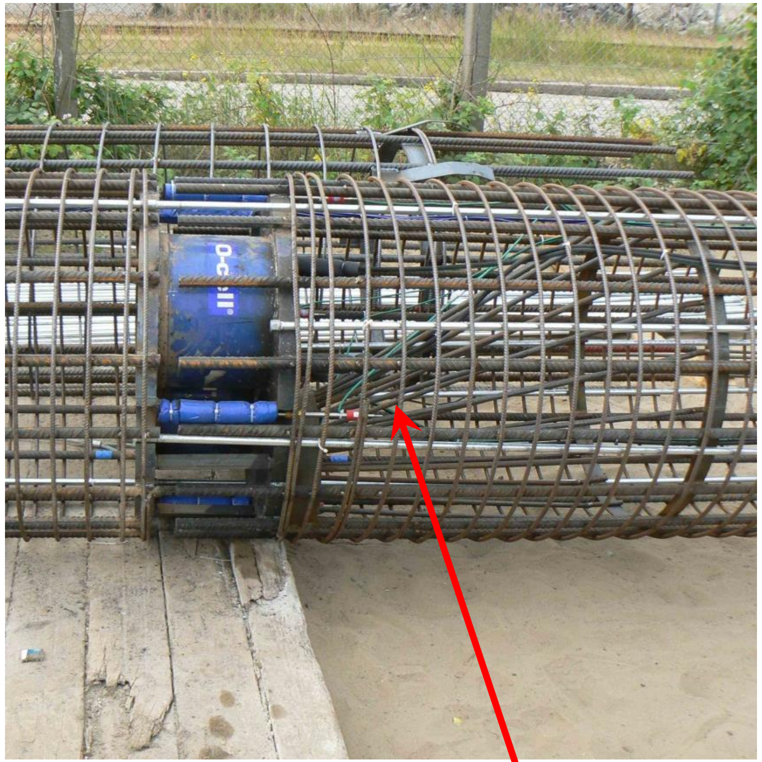




Single O-cell – Bearing Plate Assembly

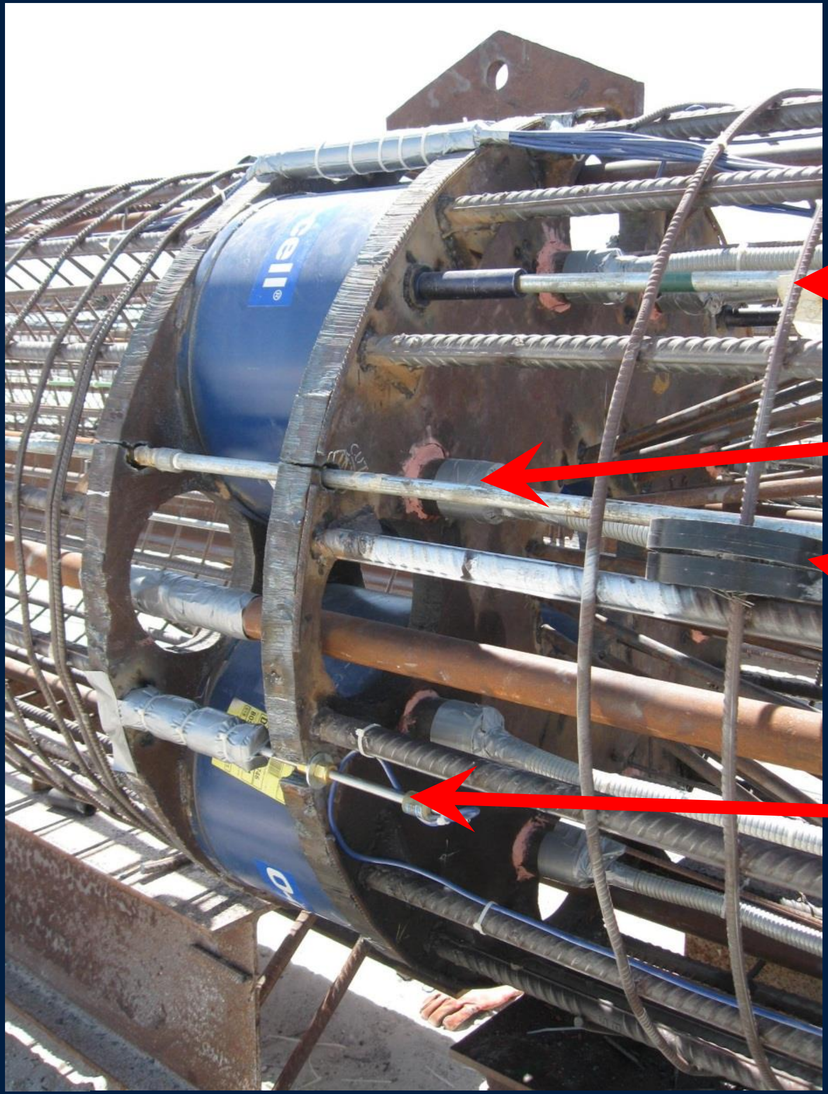
Concrete tremie pipe guide

Cone-shaped tremie guide



Offset Tremie guide

Single-level O-cell test

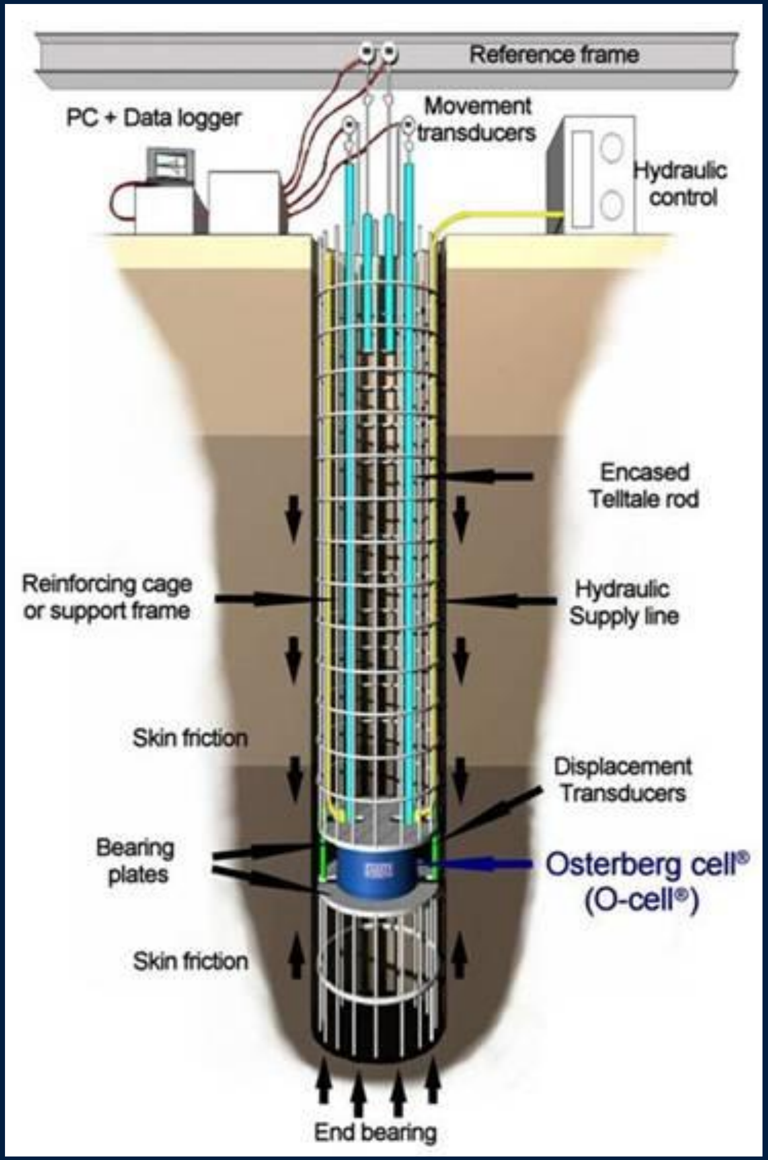


Compression telltale

Hydraulic hoses

Pile toe telltale

Expansion transducers

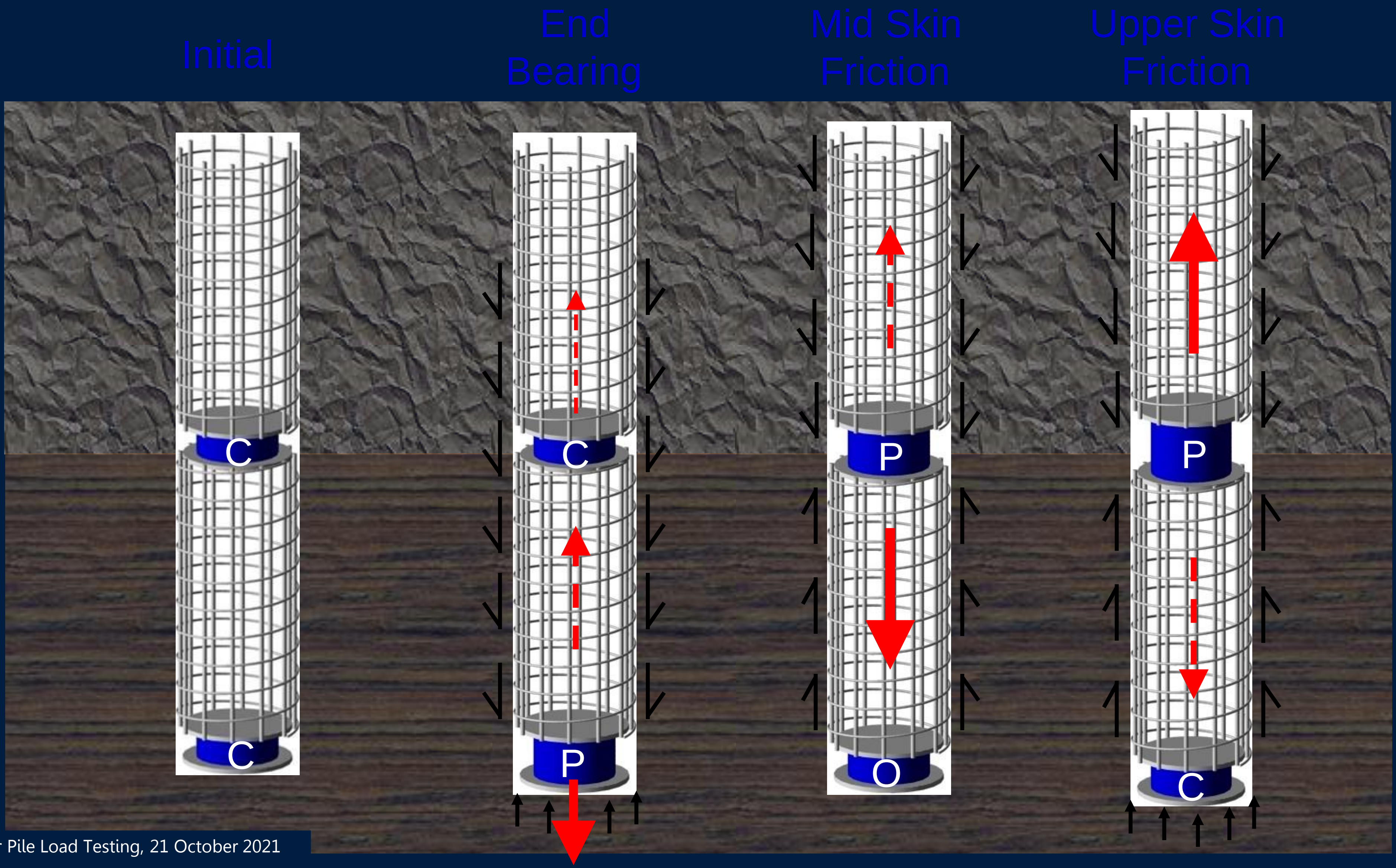


Handling of the cage with O-cell(s) and instrumentation

Once the cage with attached O-cell is carefully lifted, it is installed into the shaft excavation

Summary by Video

Multi-level O-cell tests



Comparison 48MN O-cell Test with 20MN Traditional Top Down

5MN Test

Traditional Top Down

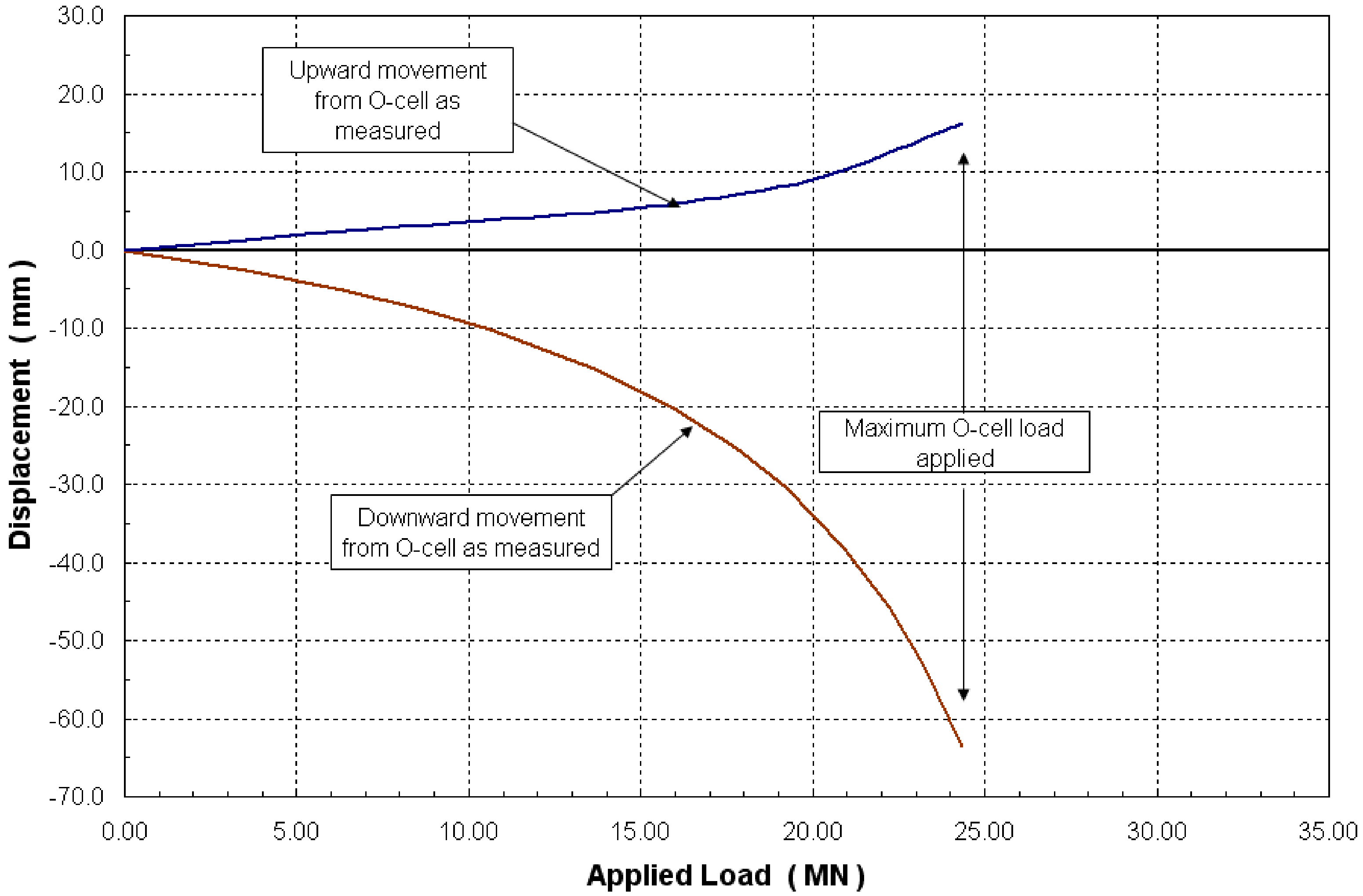
Compared to

O-cell Set-Up

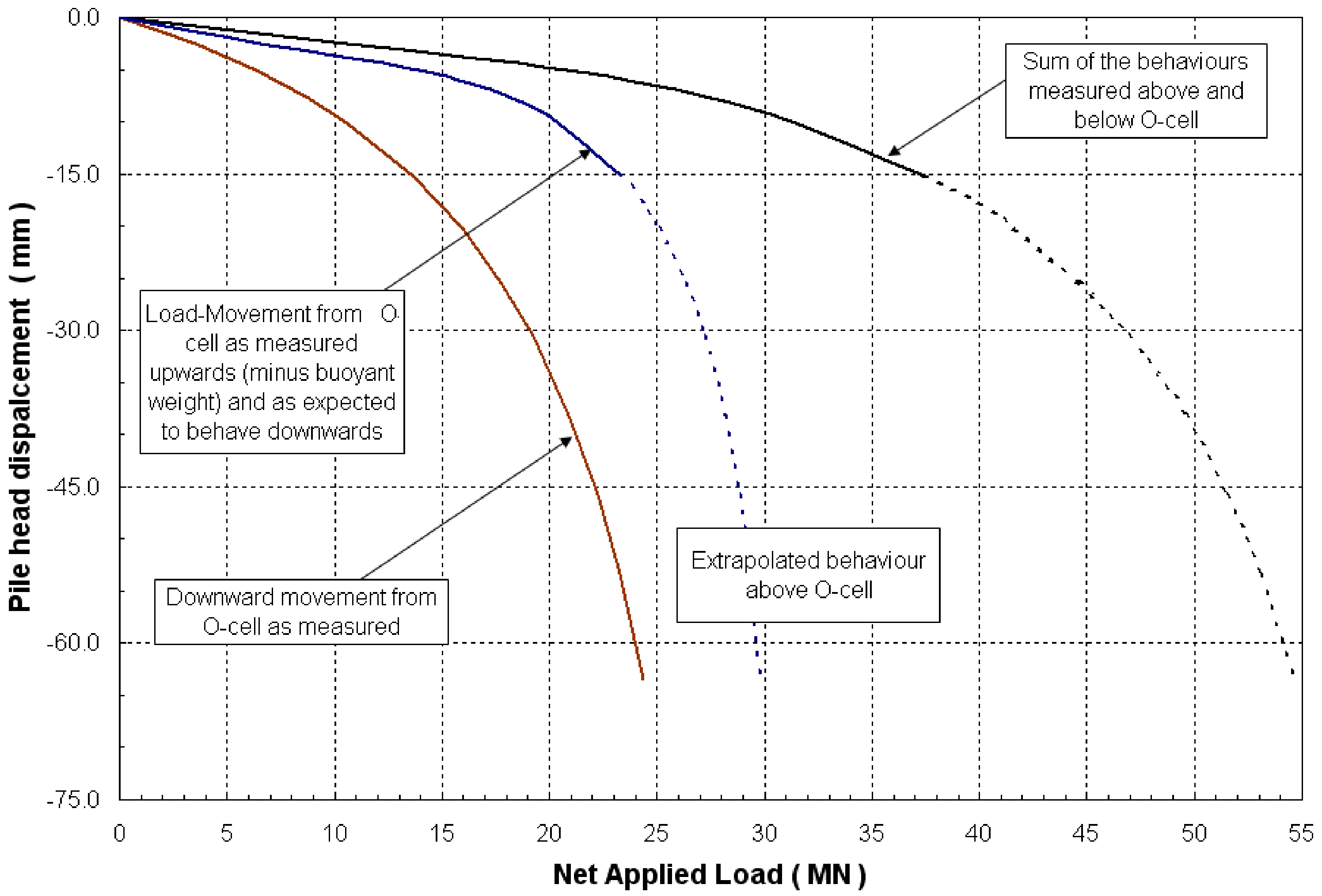
O-cell Static Load Test Benefits

- Very high loading capability (up to 300.000 kN)
- Gets load into rock sockets (or other zone of interest)
- Cost, safety and space advantages
- No additional reaction system needed
- Doubles effective jack load
- Can measure directly skin friction and end bearing
- Post-test grouting techniques allow for testing of production piles

Analysis of O-cell test results

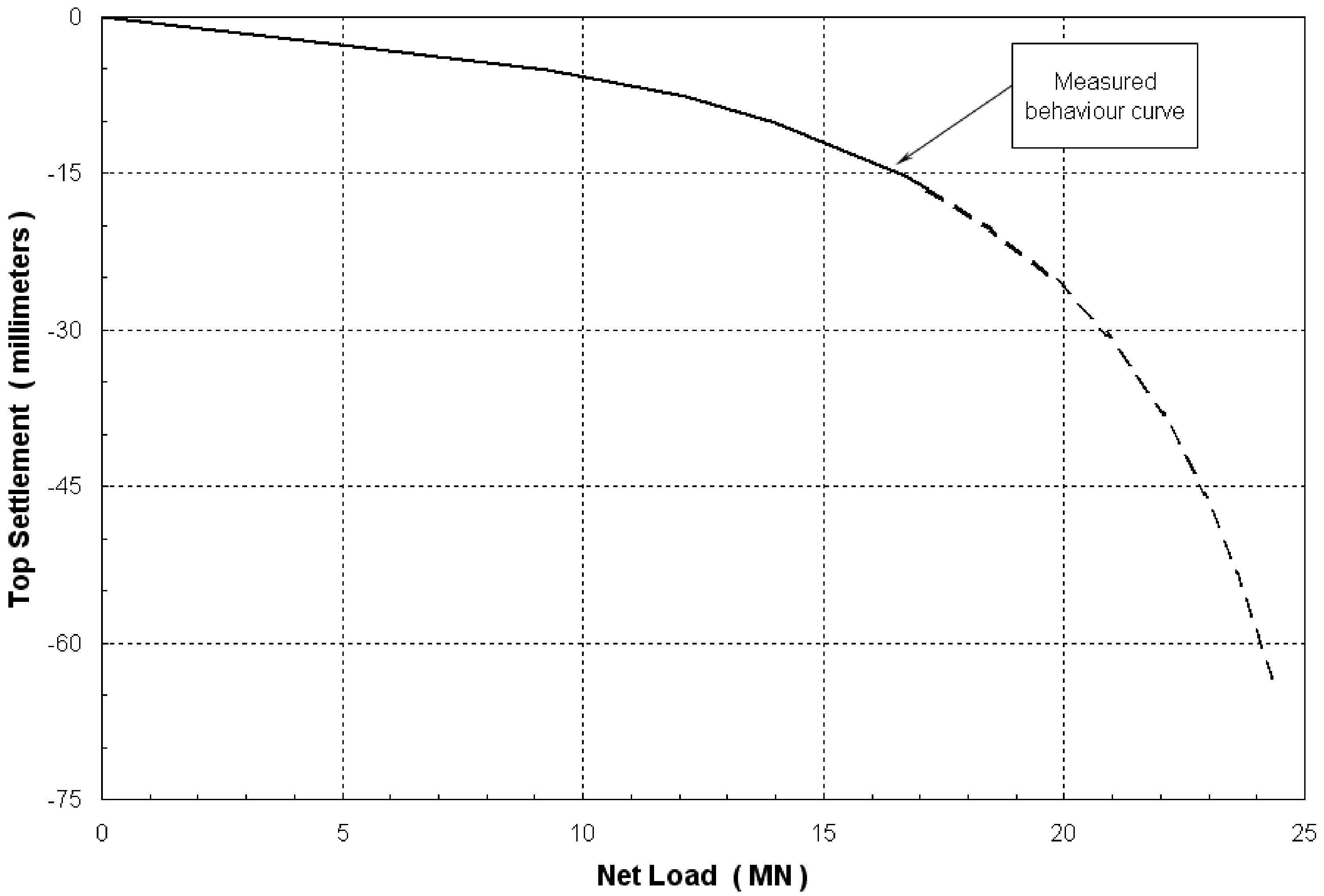


Analysis of O-cell test results



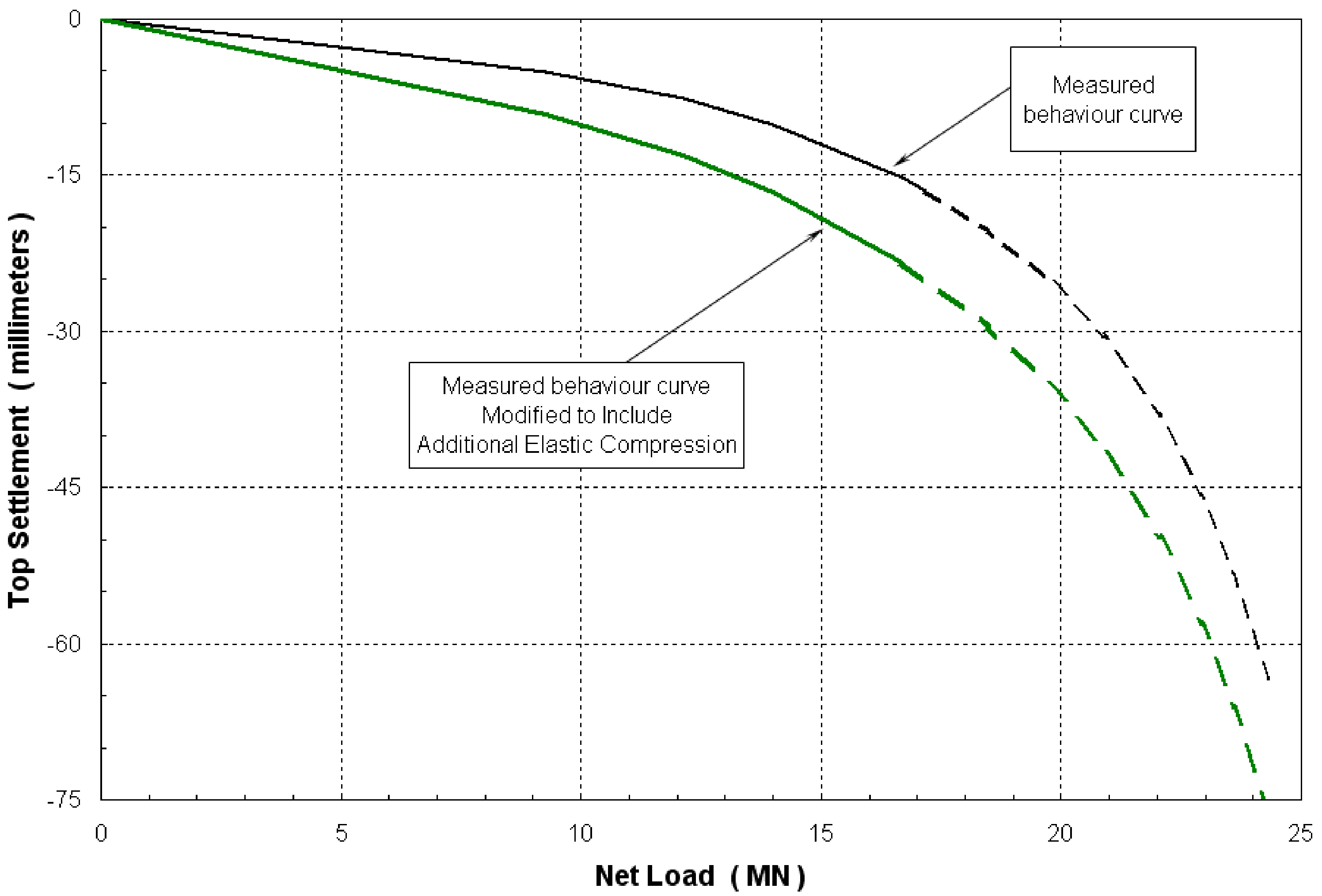
Sum of measured results

Analysis of O-cell test results



Measured behaviour Sum of components

Analysis of O-cell test results



Measured plus additional elastic shortening

Bi-Directional Pile Load Test integrated in Dutch Codes

- NTA 4614-3, 2012: Covenant high-rise buildings – Part 3: Structural safety
- NEN 9997-1+C2, 2017: Geotechnical design of structures - Part 1: General rules
- NPR 7201+A1, 2020: Geotechnics – Determination of the axial bearing capacity of foundation piles by pile load testing

NTA 4614-3
(nl)

NEN 9997-1+C2
(nl)

NPR 7201+A1
(nl)

NTA 4614-3 (2012)

Nederlandse technische afspraak

NTA 4614-3
(nl)

Convenant hoogbouw - Deel 3: Constructieve veiligheid

Covenant high-rise buildings - Part 3: Structural safety

- NTA: focus on structural design and safety for high rise buildings (most common: >70 m)
- Additional criteria, next to current codes
- Motive: the increasing construction of high buildings to comply the demand of homes and offices in the Netherlands
- Including attention points related to the geotechnical design (section 9)
- According NTA 4614-3: high rise building are covered by geotechnical category 3*
- Use of different (economical) pile bearing factors (α-factors) is only allowed based on pile load tests**
- NOTE: because of the expected high loads of high-rise building, traditional top down pile load test is not always possible/ safe, the use of load-cell in the pile is a good suggestion, measuring the end and shaft bearing capacity

NEN 9997-1 (2017)

Nederlandse norm

NEN 9997-1+C2

(nl)

Geotechnisch ontwerp van constructies -
Deel 1: Algemene regels

Geotechnical design of structures -
Part 1: General rules

- NEN: about the geotechnical design of structures, including **pile foundations**
- When geotechnical category 3 is applicable*, additional tests** are **necessary**
- And when there is no similar experience with this type of pile and installation method in combination with high loads, deep foundations and complex soil conditions, **pile load tests** are necessary
- But also to check the installation method, to determine the geotechnical pile bearing capacity and load displacement behaviour
- to determine more **realistic / economical** pile bearing capacity factor (α-factors) without the negative impact of reduction of the cone resistance, to optimize the pile foundation
- Correlation factors of pile load test are included in the tables A9a and b in the appendix
- Partial resistance factor of compression piles (ξ_R) is **1,15** in stead of 1,2 (related to CPT)

NPR 7201+A1 (2020)

- NPR: about the determination of the axial bearing capacity of foundation piles by pile load testing
- 5 classes of pile load tests: A1, A2, B, C and D
- Bi-directional pile load testing not explicitly described in this code, but can be considered as a full scale static load test (SLT) because of the same duration of the load step and because there are no dynamic effects
- Bi-directional pile load tests are suitable for all classes, but recommend with instrumentation for class A1 and A2

Nederlandse praktijkrichtlijn

NPR 7201+A1

(nl)

Geotechniek - Bepaling van het axiaal draagvermogen van funderingspalen door middel van proefbelastingen

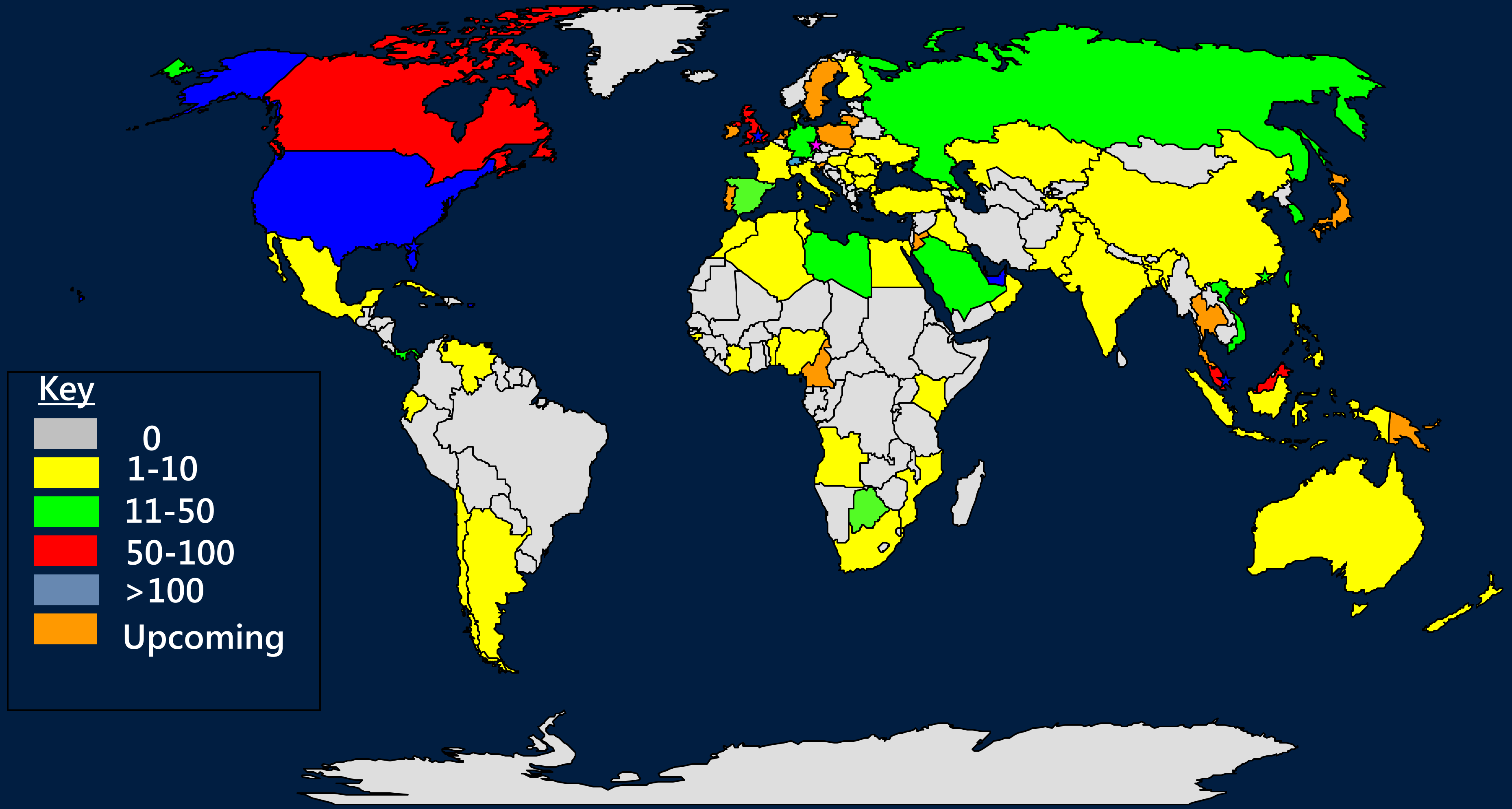
Geotechnics - Determination of the axial bearing capacity of foundation piles by pile load testing

Applications and Project Examples

- Bored piles (wet and dry)
- CFA piles
- Fundex Piles
- Driven Piles
  - Cast in-situ (with and without permanent steel casing)
  - Precast
  - Spun piles
  - Steel tubular piles
- Barrettes

- Towers/skyscrapers
- Buildings
- Bridges
- Metros/MRTs/Rail
- Ports
- Wind turbines
- Power plants / industrial
- Highways

O-cell Tests World-wide



I-70 Bridge over the Mississippi River, St. Louis, Missouri, USA (1)

- The rock socket was about 7m deep and 3350mm in diameter in very hard limestone.
- 4x 870mm O-cells were placed at the base of the toe
- And loaded to 320 MN, 150% of their rated capacity

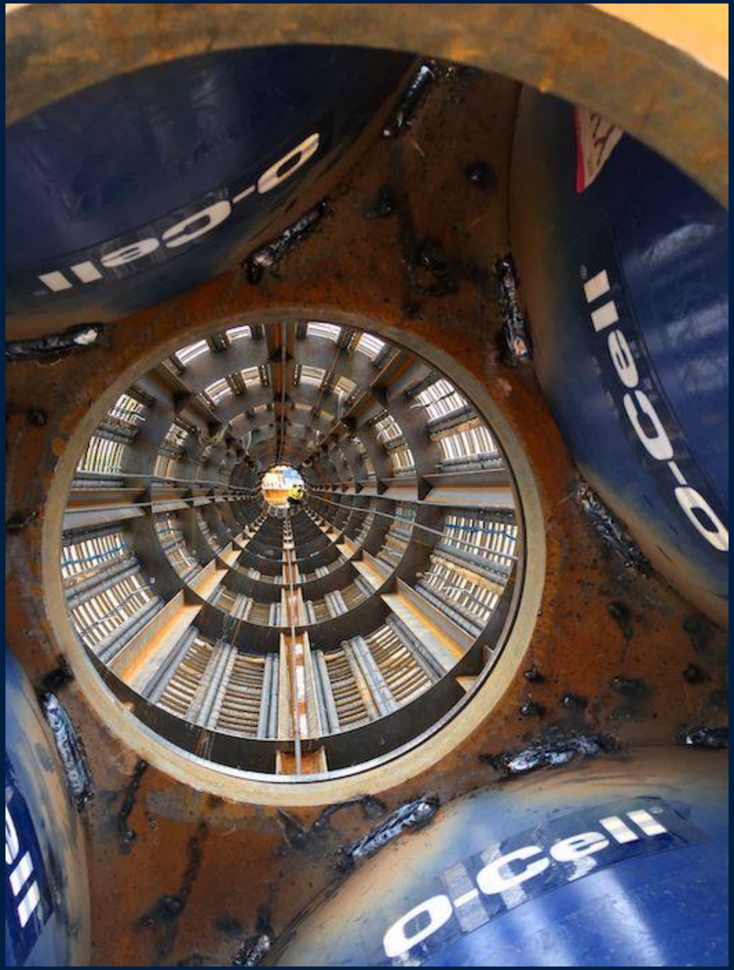
I-70 Bridge over the Mississippi River, St. Louis, Missouri, USA (2)

Ohio River Bridges Downtown Louisville, Southern Indiana, USA (1)

- Rock socket in limestone, length to be optimised
- Use of 4 O-cells of 870 mm at singel level
- At 1.1 m above pile toe
- Pile diameter: 2.2 m

Ohio River Bridges Downtown Louisville, Southern Indiana, USA (2)

USA-Canada bridge project



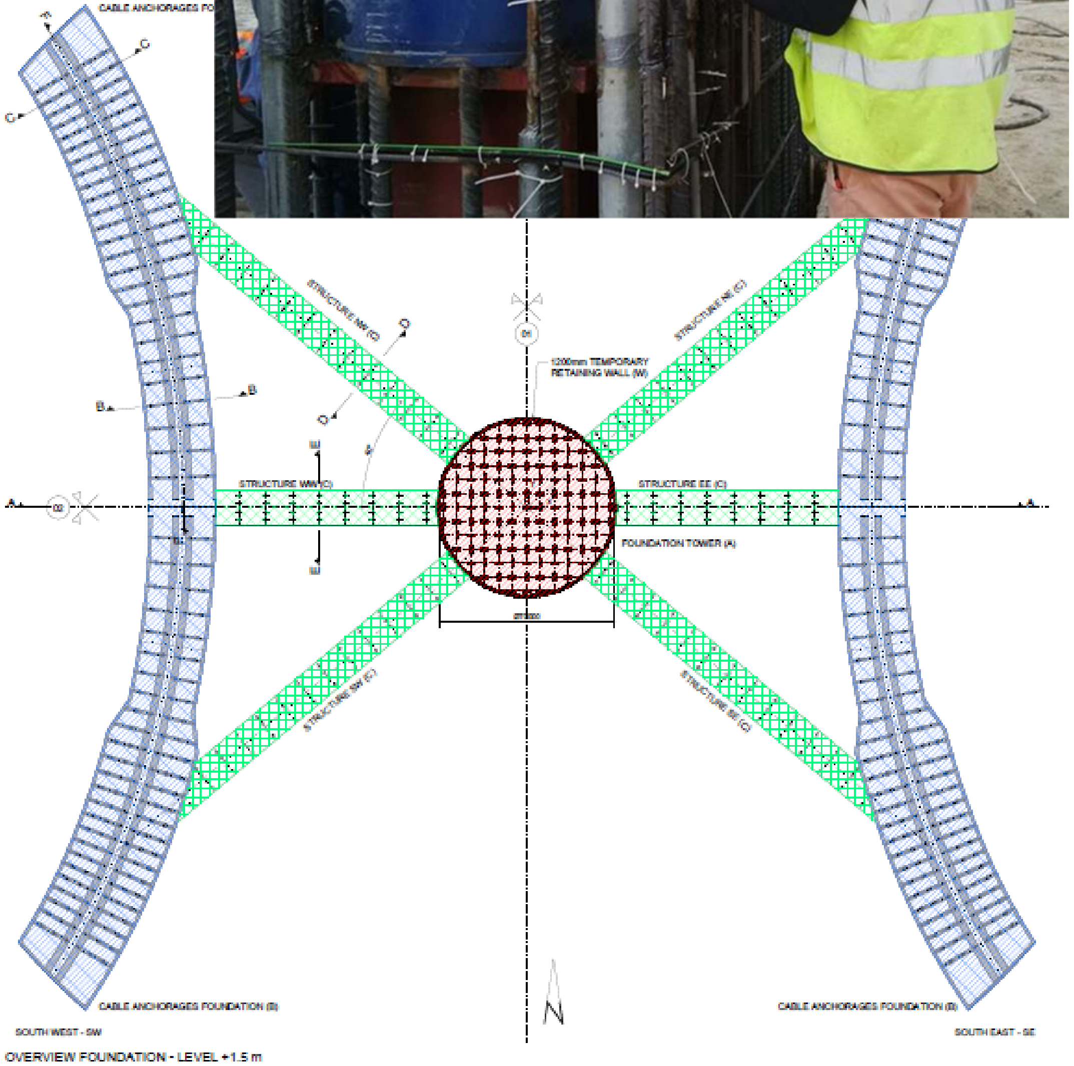
- Gordie Howe International Bridge
- 2.5 km long Canada – US border crossing Ontario and Michigan
- Over the Detroit River
- Under construction, open in 2024

Dubai Creek Tower UAE (1)

Tallest building in the world with a minimum of 828 m - even heiger than the neighbour buidling, the Burj Khalifa

Dubai Creek Tower UAE (2)

- 3 Test Barrettes to 80-90 m depth to determine the Ultimate Compression Capacity
- With 3x 890 mm O-cells on 2 levels and a maximum mobilized reaction of 363 MN (world record!)



Incheon Bridge project, South Korea (1)

Length: 12 km
Height pylons: 239 m
Center span: 800 m
Clearance height: 74 m

Incheon Bridge project, South Korea (2)

- 4 bi-directional pile tests
- within bored piles to about 60-70 m depth
- With a diameter of 2.4 to 3.0 m
- and a permanent casing through the sea bed and into the soft rock at 38-48 m
- Maximum loading force of 279 MN
- With multiple O-cells on multiple levels

Okavango River Bridge Botswana

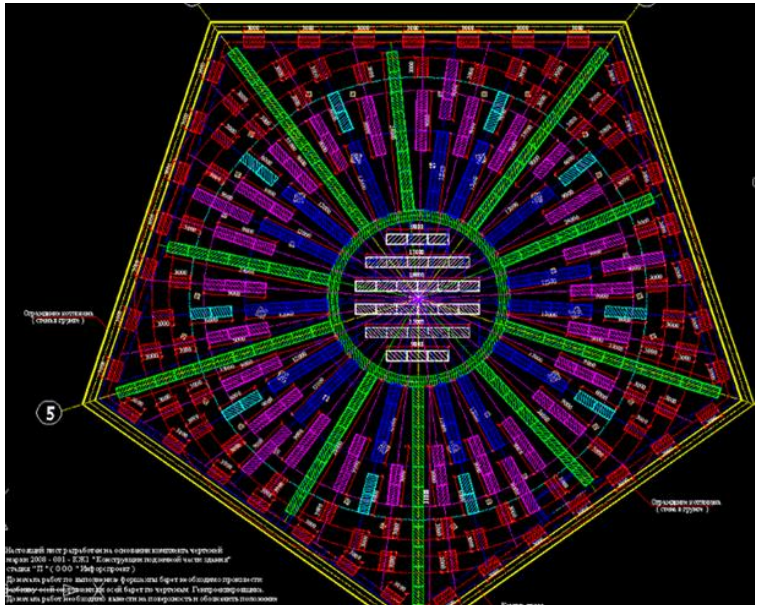
Testing with loads ranging from 6.5 to 14 MN, comprising 1 or 2 300 mm O-cells, in bored piles with a length of 28 to 50 m

Lahkta Centre project St. Petersburg (1)

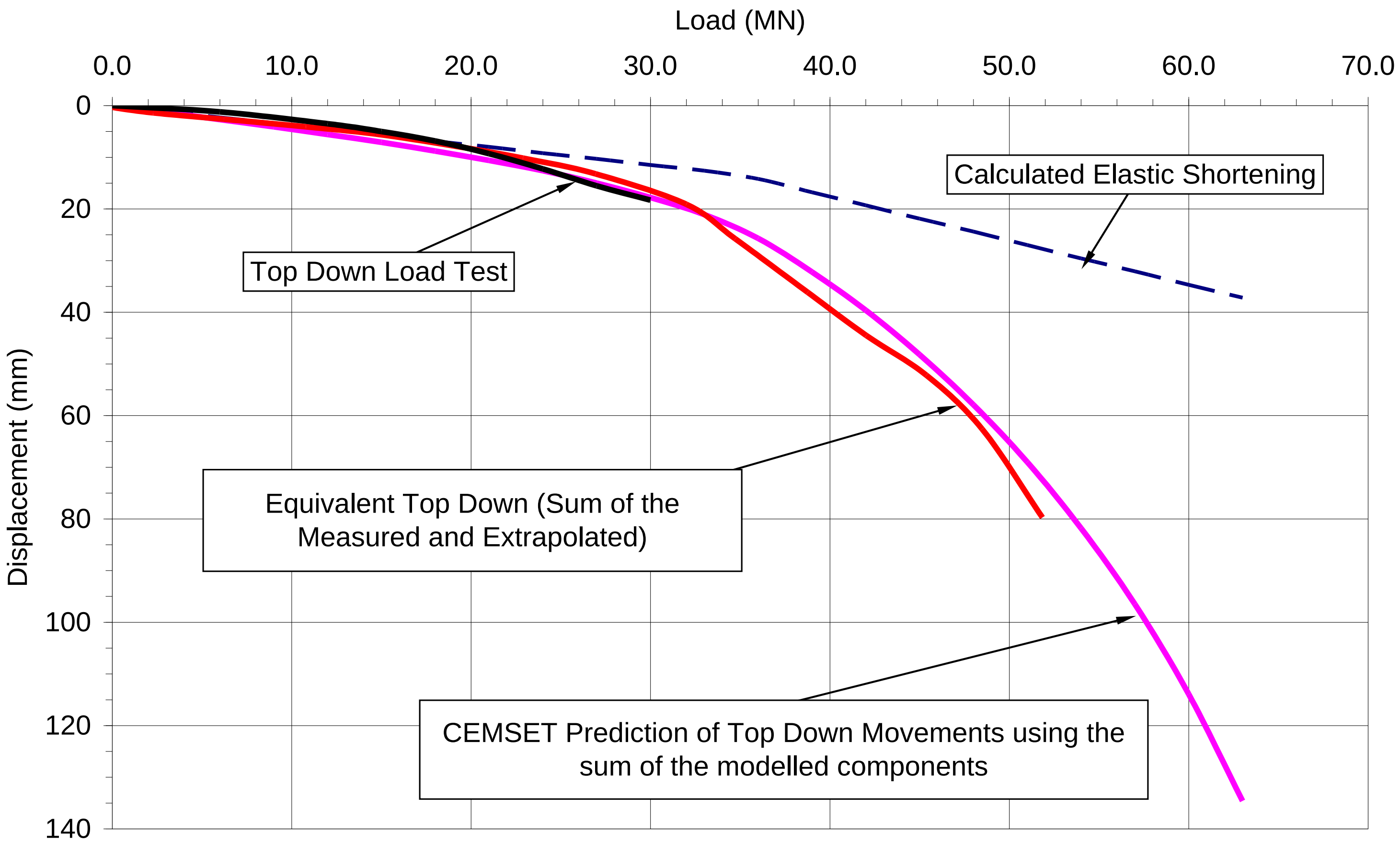
- O-cell pile load testing
- within a barrette
- constructed to 60 m depth
- with a potential O-cell capacity of 90 MN

Tallest skyscraper in Russia/ Europe at 462 m high

Lahkta Centre project St. Petersburg (2)



Lahkta Centre project St. Petersburg (3)



Tallest skyscraper in Russia/ Europe at 462 m high

Test results provided confidence on the correlation of results from O-cell and traditional top down methods

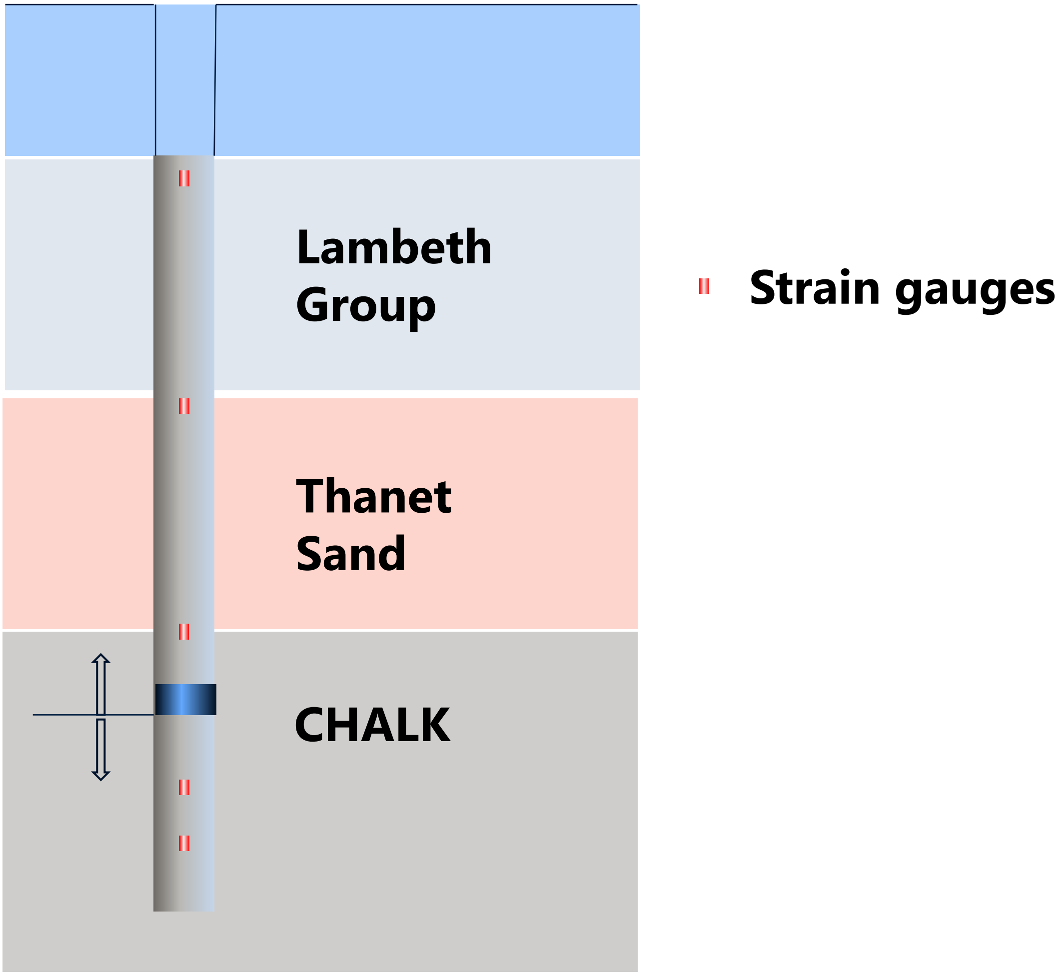
Project in UK: Spire London (1)

Spire London will be Western Europe's tallest residential tower, standing just over 235 metres tall, with 67 floors.

Spire London (2)

2100 mm Diameter test piles
57.2 m Deep
15.6 m into the Chalk
47.2 m Concreted length

White Chalk graded as A to C in the top 5m and Grade A below; Assumed unit friction in the design 300 kN/m²

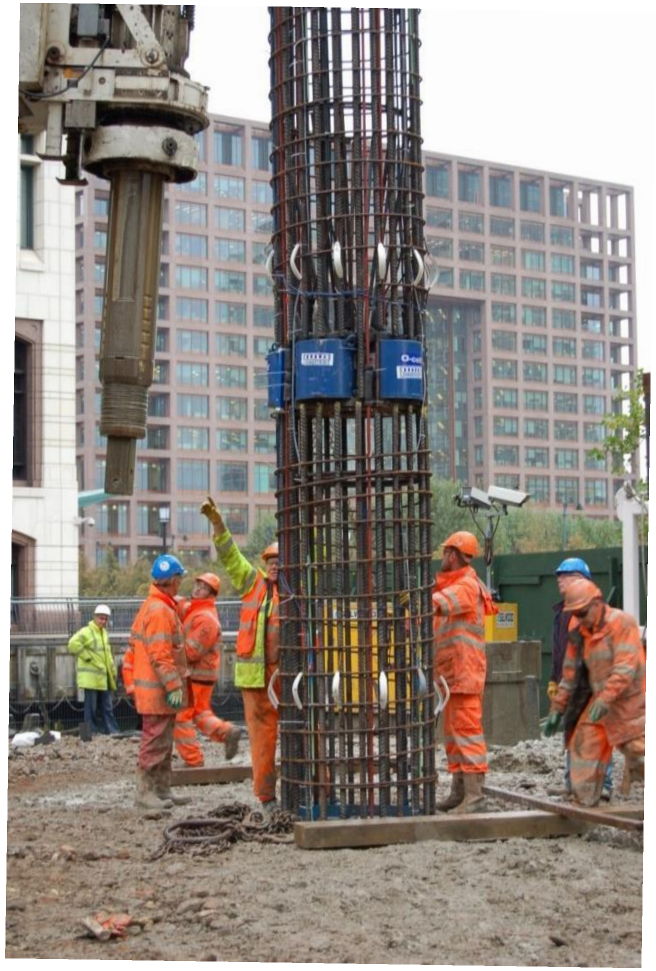


Spire London (3)

- 3x 680 mm O-cell arrangement
- 12 m above the toe
- Nominal loading capacity of 96 MN

Canary Wharf London

Canary Wharf, London



1200 & 1500 mm preliminary pile tests. Loading capacity 60 MN

Crossrail London

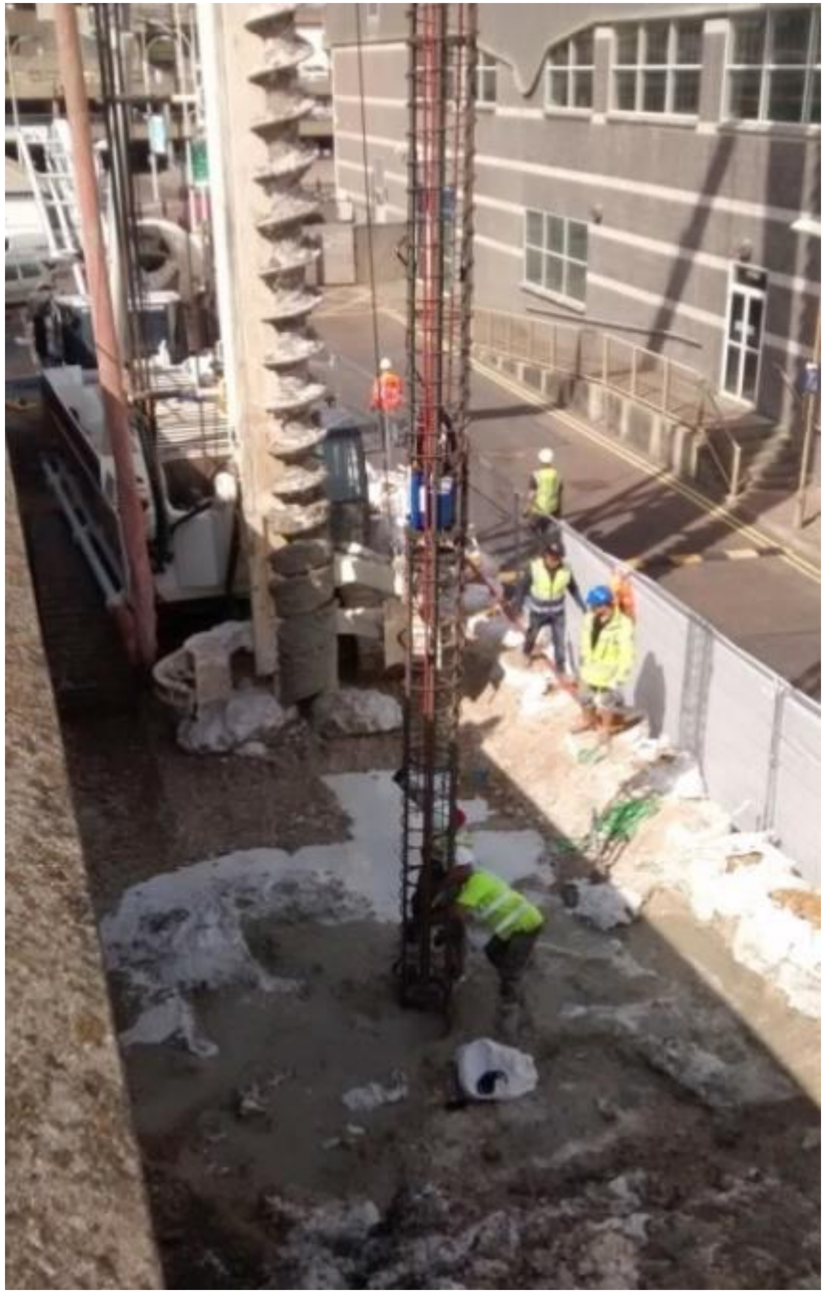
Farringdon Station, London

1500mm preliminary pile test
Loaded to 80 MN & a 750mm

2012: 1200mm completed
2013: 2100mm

Brighton Marina (1)

With Continues Fligt Auger (CFA) piles



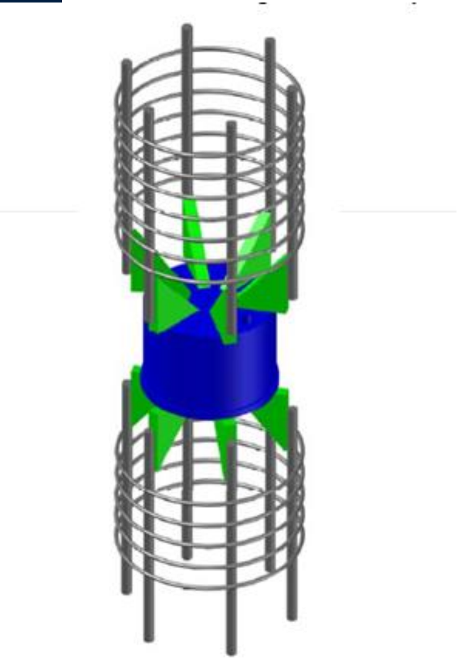
Brighton Marina (2)

Single 330 mm O-cell fitted 4.1 m above the toe.

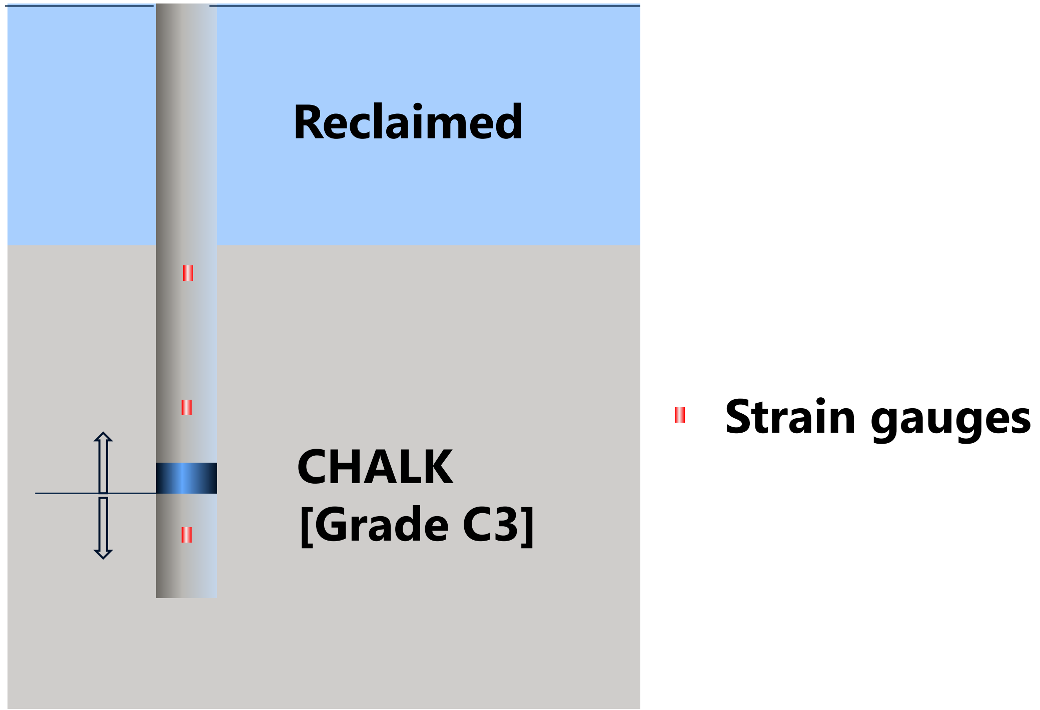
Chalk from 9.0 m described as Grade C3.

Assumed friction for design 150 to 200 kN/m^2

Mobilised unit friction 220 to 500 kN/m^2



3D rendering of reinforcing cage with attached O-cell assembly



Nominal CFA Pile diameter 600 mm
Pile length 20.1 m constructed with Grout

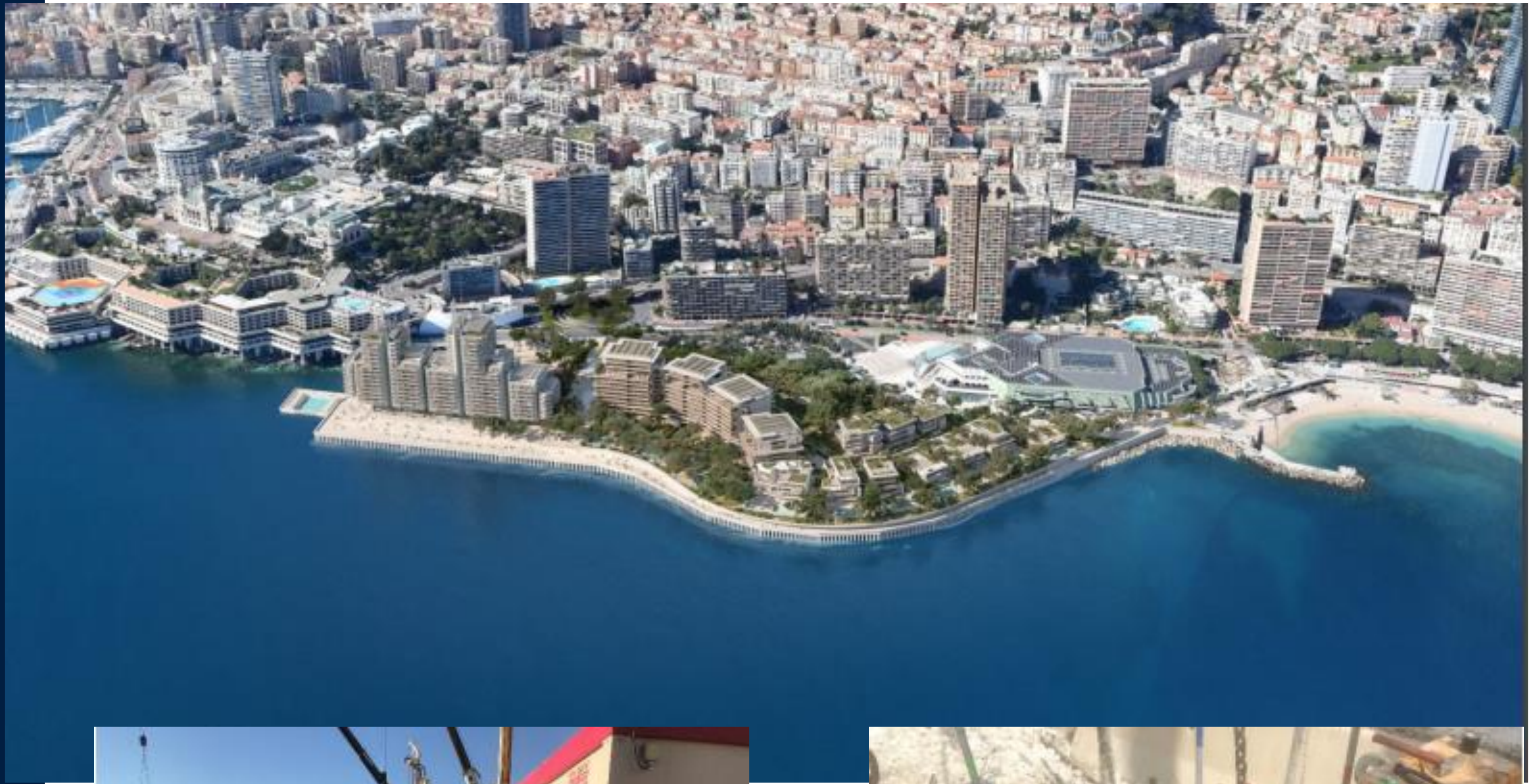
Infrastructure work Antwerp Belgium

4x24 MN Barrettes,
up to 45 m depth

Saint-Brieuc France Offshore wind farm project

Testing of onshore piles to gather data for the design of foundation

Portier Cove land extension project in Monaco



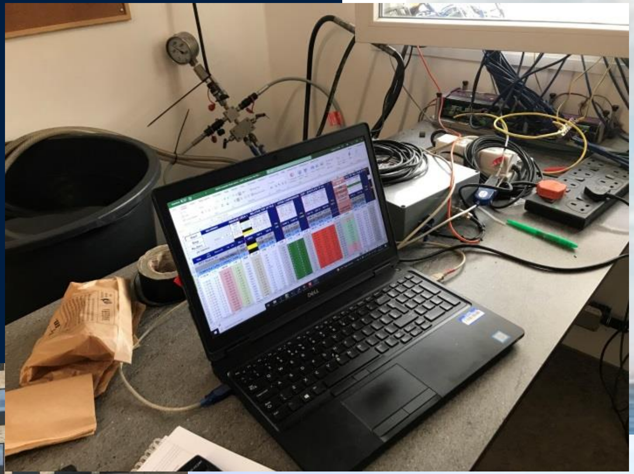
Testing underway with a very small test area footprint

Assembly lowered into final position

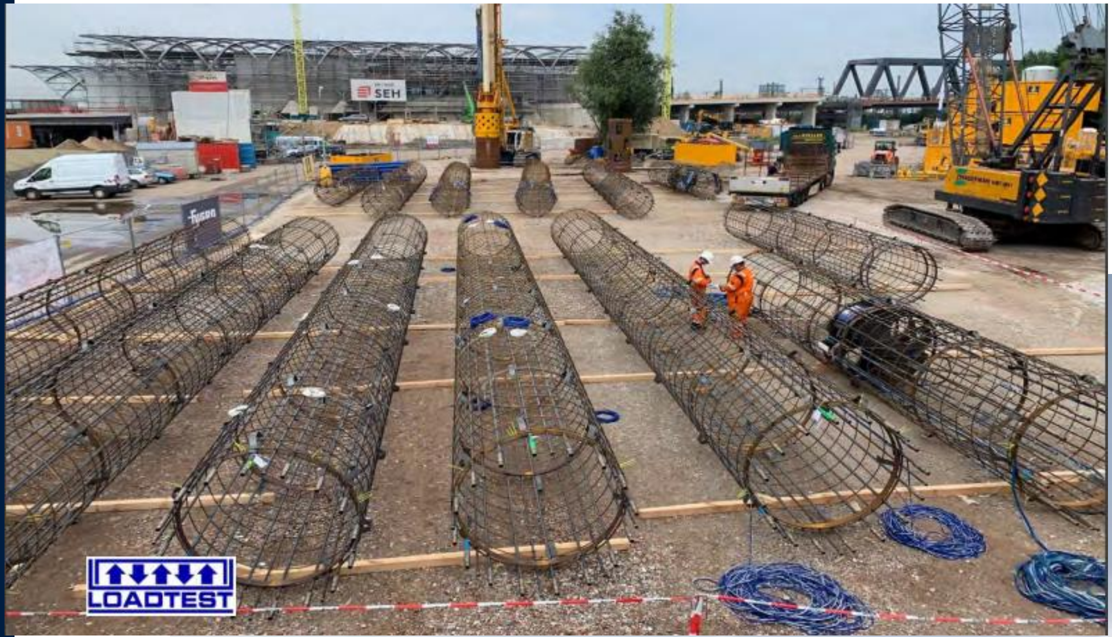
Aarhus projects in Denmark

Transformation of the Aarhus Waterfront

Lighthouse project 2.0, Denmark’s tallest residential tower



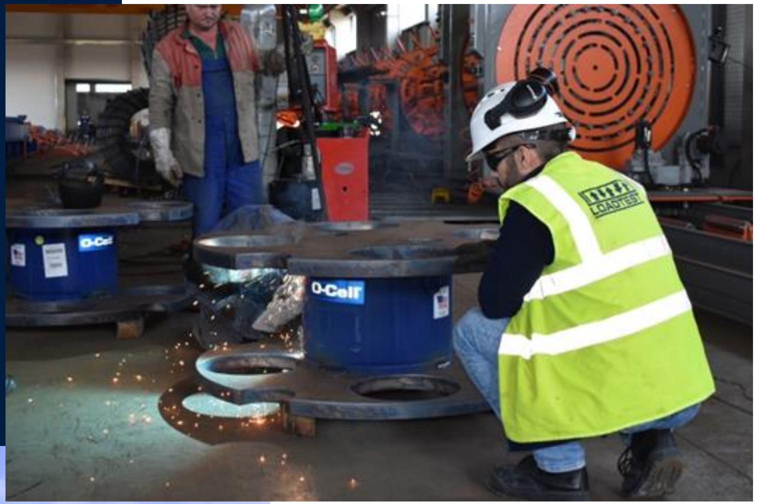
Elbtower project in Hamburg

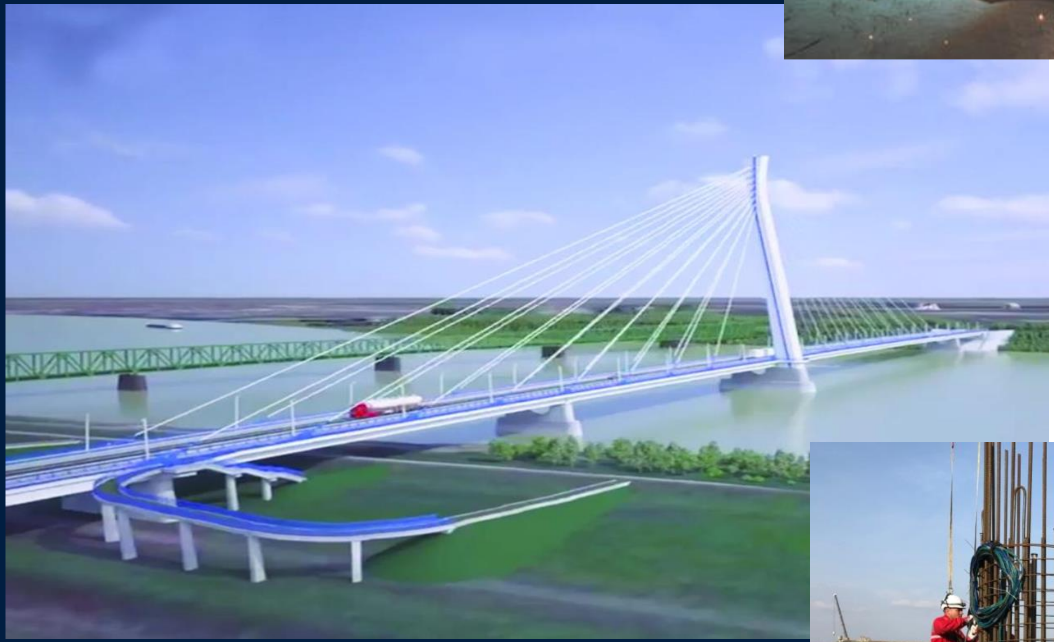


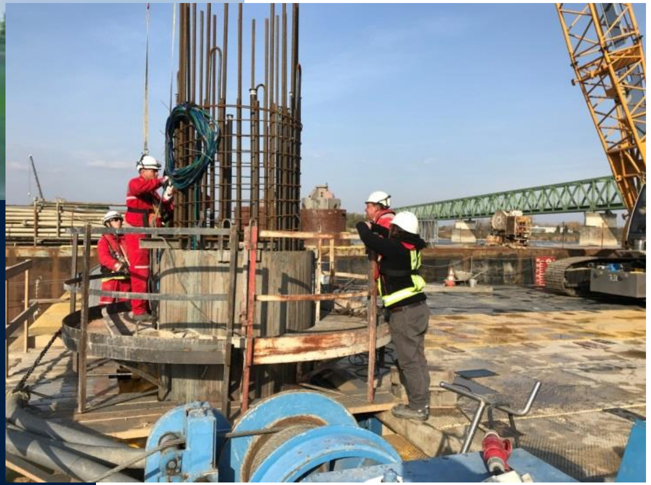
Preparing the instrumentation to the cages of the 110 m length bored piles

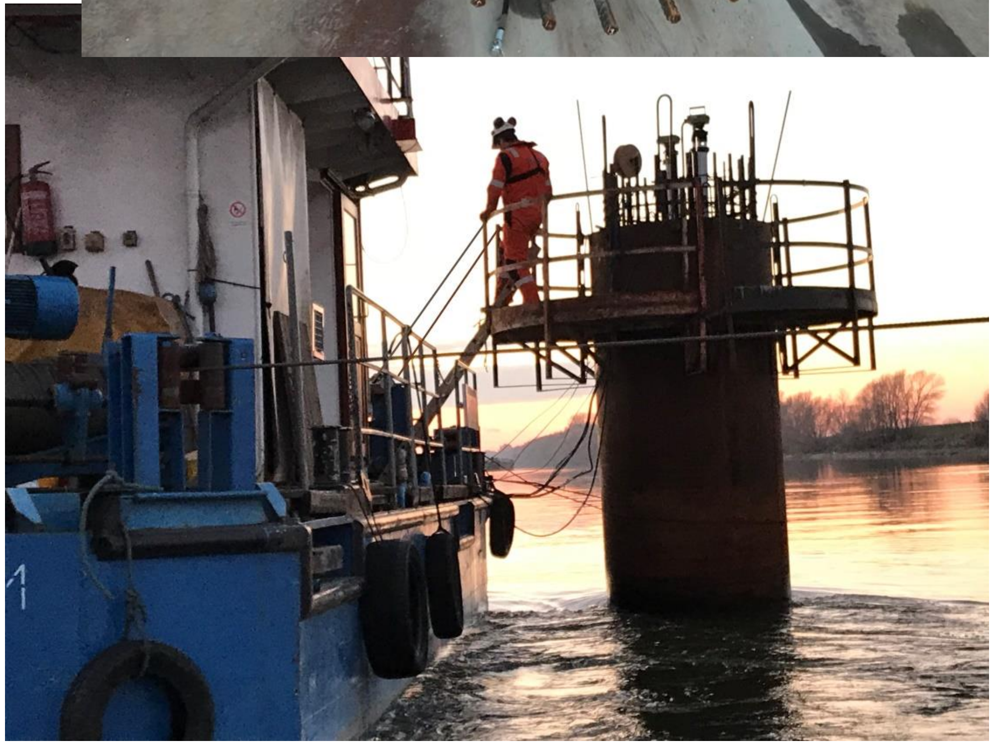
Projected impression of the 244 m high Elbtower, the third tellast skycraper in Germany

Danube River Bridge project Hungary-Slovakia



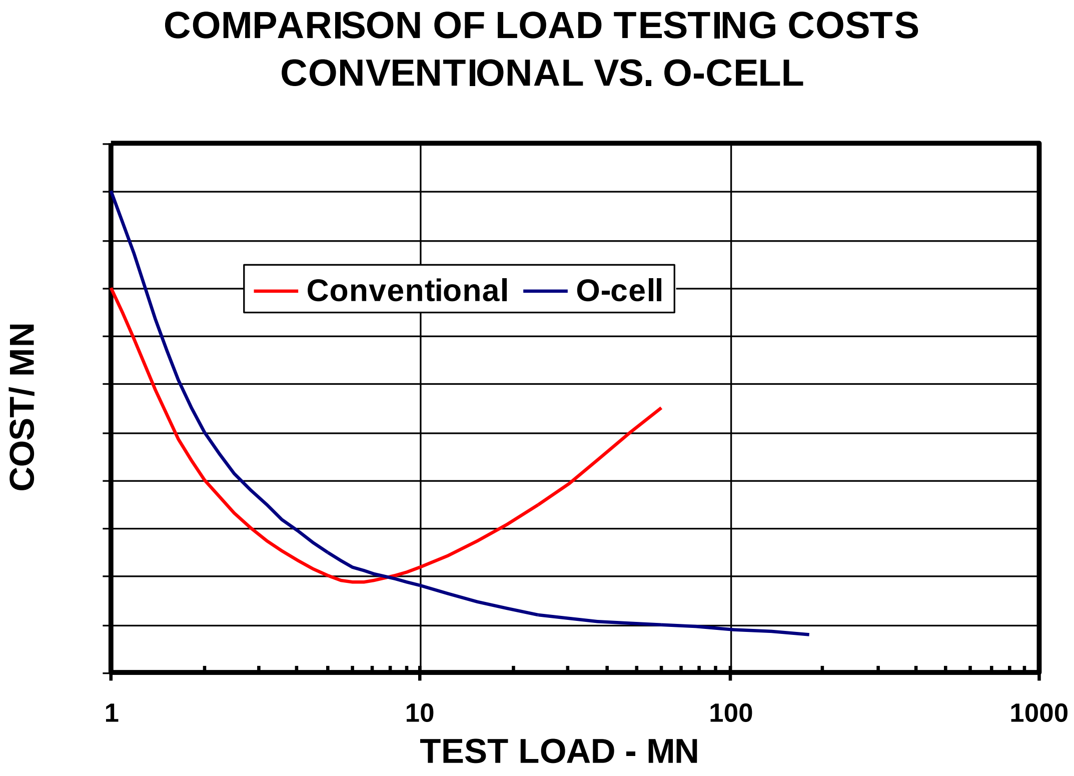






Summary, conclusions and call to action! (1)

- Robust and reliable full scale static pile load testing system, revealing long term pile-soil behaviour
- High loads are possible, up to 322 MN
- Economical from about 6-7 MN, in comparison to traditional top-down testing
- Safe and lean execution with a small footprint
- Suitable for poorly accessible / confined project sites



Summary, conclusions and call to action! (2)

- Testing and interpretation of bi-directional pile load tests are covered in the (Dutch) codes
- Lot of international experience (more than 5000 test in 60+ countries)
- Base of foundation optimisation and design and installation verification
- Especially suitable for high-rise buildings and special structures (like bridges) with high loads
- Investment to create value and save money in stead of additional costs
- **Call to action: lets start tomorrow with bi-directional testing in the Netherlands!**

Our partners

"

Thank you for your attention!

Questions?

Unlocking **Insights**
from **Geo-data**

Version 2.0 - 2 September 2021

Notes