

Geotechnical Design and Piling in Weak Rock

Ichthys LNG Project, Australia

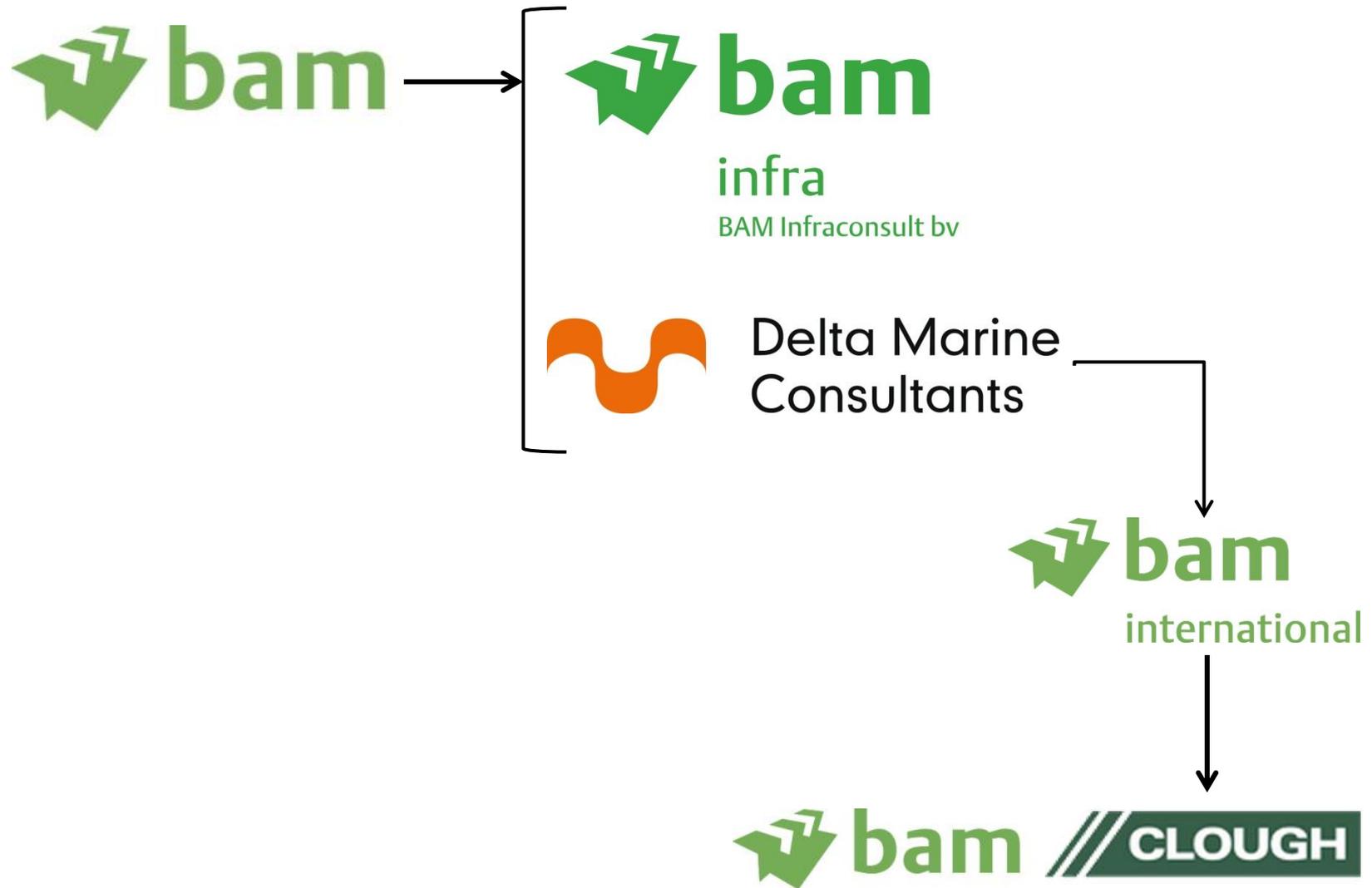


KIVI ALV + Geotechniek in de Offshore
Delft, 6 Februari 2014

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BAM Infraconsult / DMC



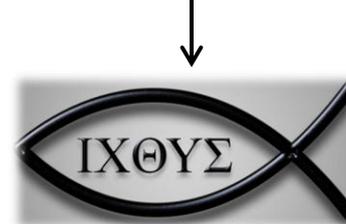
Organisation



Ichthys Project



Fossiele vissen nabij gasveld



Ichthys Project



50/50 Joint Venture

Modular Offloading Facility (MOF):

€110 Mln

Product Loading Jetty:

€290 Mln

- Geotechnical Design
- Structural Design
- Drawings

Design Team:

A panoramic view of the Perth skyline in Western Australia, featuring several high-rise buildings and a clear blue sky.

Perth

A night view of the Singapore skyline, showing illuminated skyscrapers and a modern architectural structure.

Singapore

A modern, multi-story office building with a glass facade, situated in an urban environment.

Gouda

Other Dutch Contractors

Van Oord

Capital Dredging

€567 Mln



Dockwise (Fairstar)

Module Transport

€56 Mln



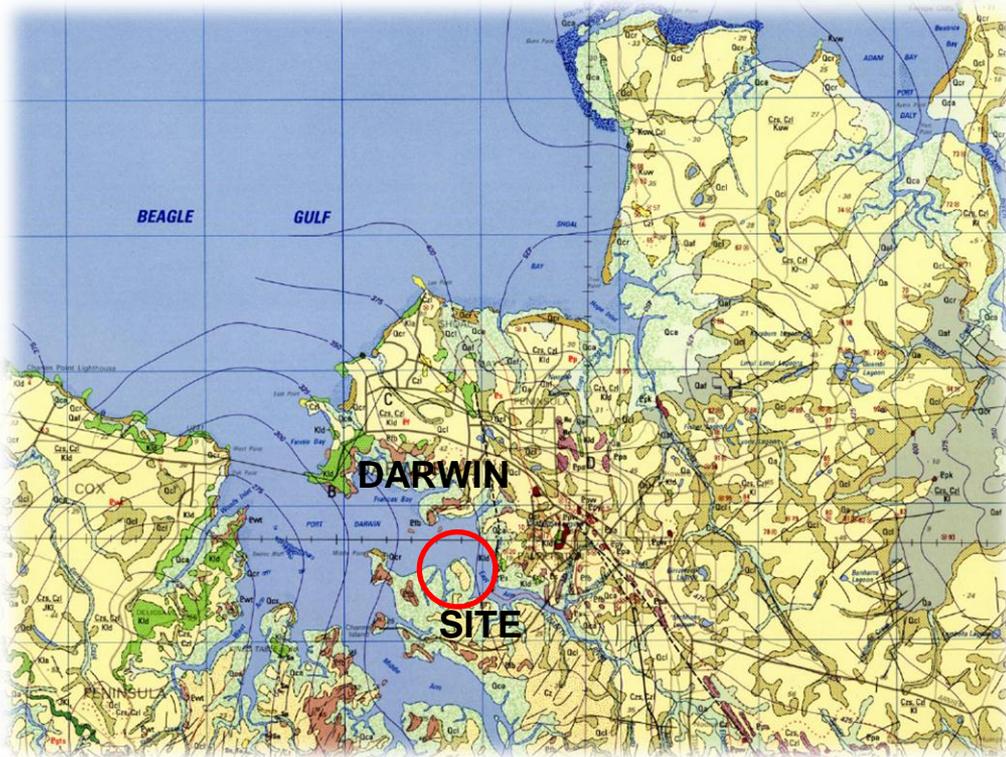
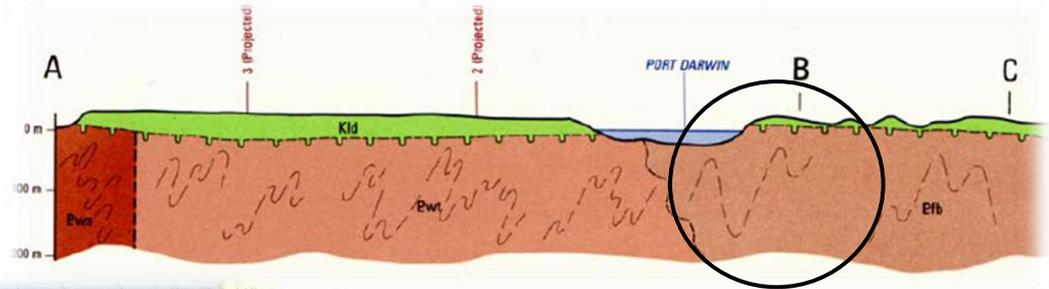
Boskalis

Trench Dredging + Landfall

€200 Mln

Site Conditions

- Recent soils – followed by Metasiltstone, Phyllite & Sandstone
- Quarts pebbles in between
- Very steeply bedded
- Foliated
- Quartz veins

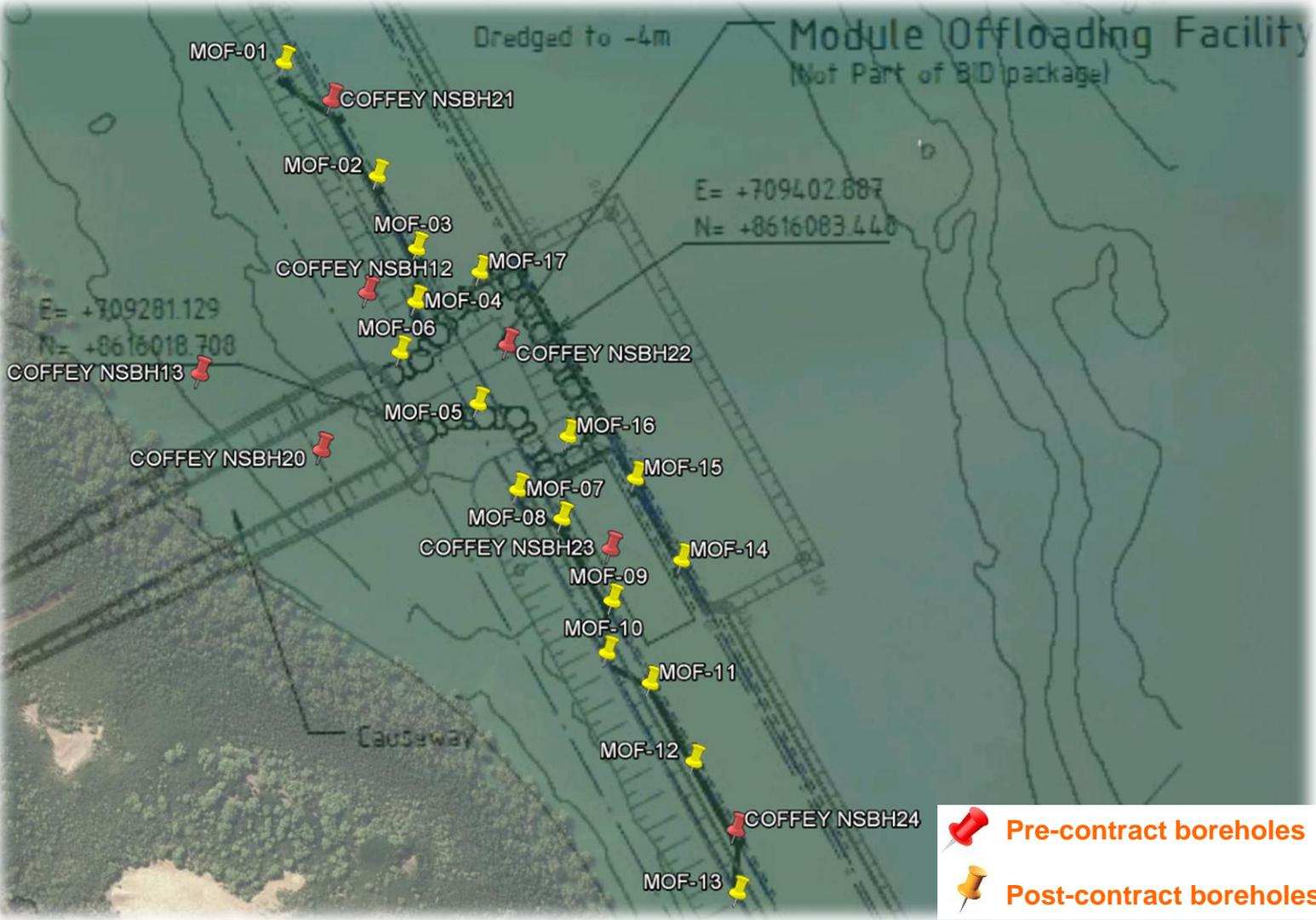


Challenges

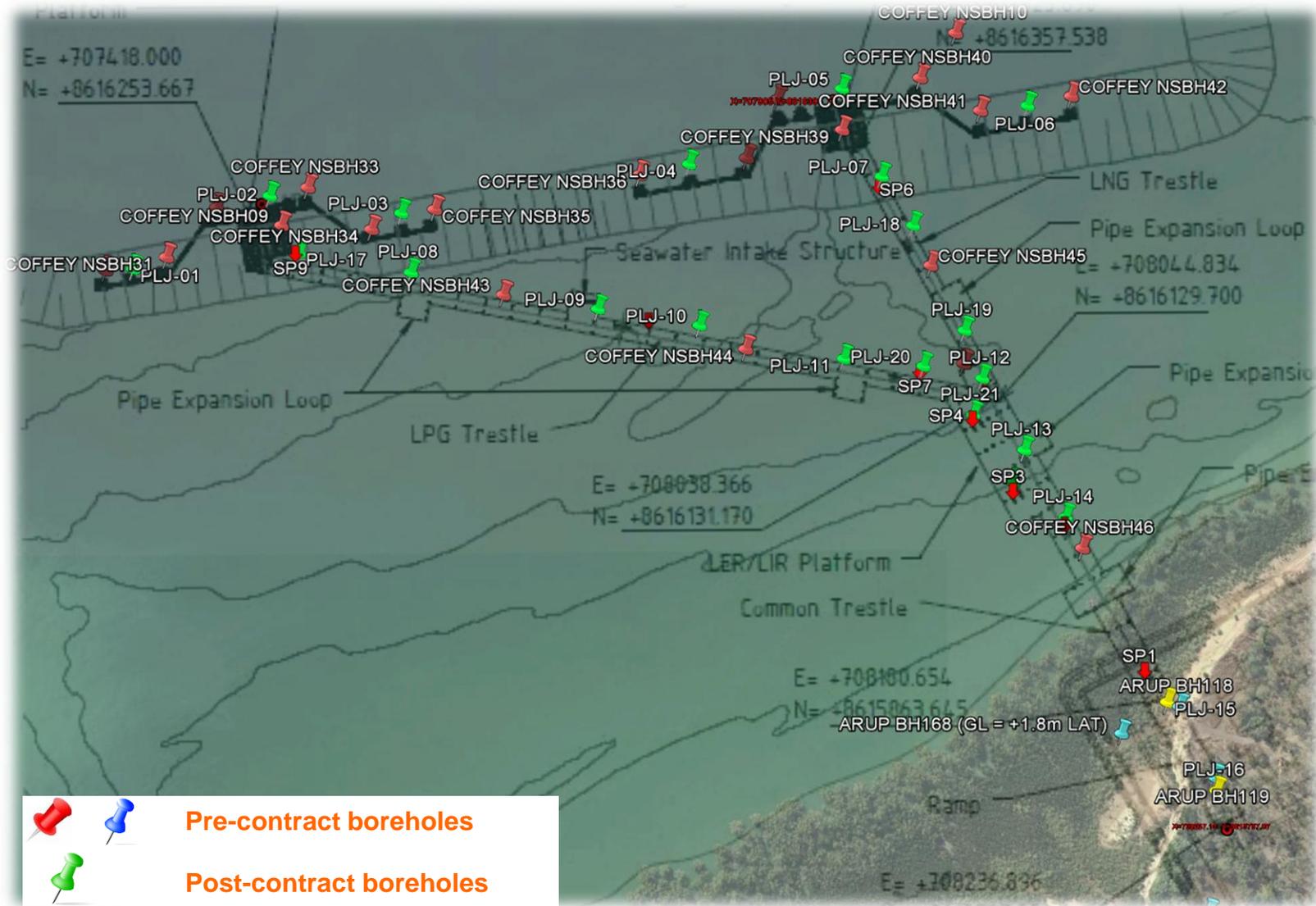
- Softening in presence of free water
- Steep inclined defects: clay filling
- Varying strength
- Possible pile driving issues



Soil investigation MOF



Soil Investigation Jetty



Additional Soil Investigation



- During Basic Design
- Including DMC Site Representative
- Rotary drilling PQ3 triple barrel wireline coring
- Exploration rig -> good control



Lab Testing

- Material properties
- UCS
- Point Load
- Slake Durability

Example cores

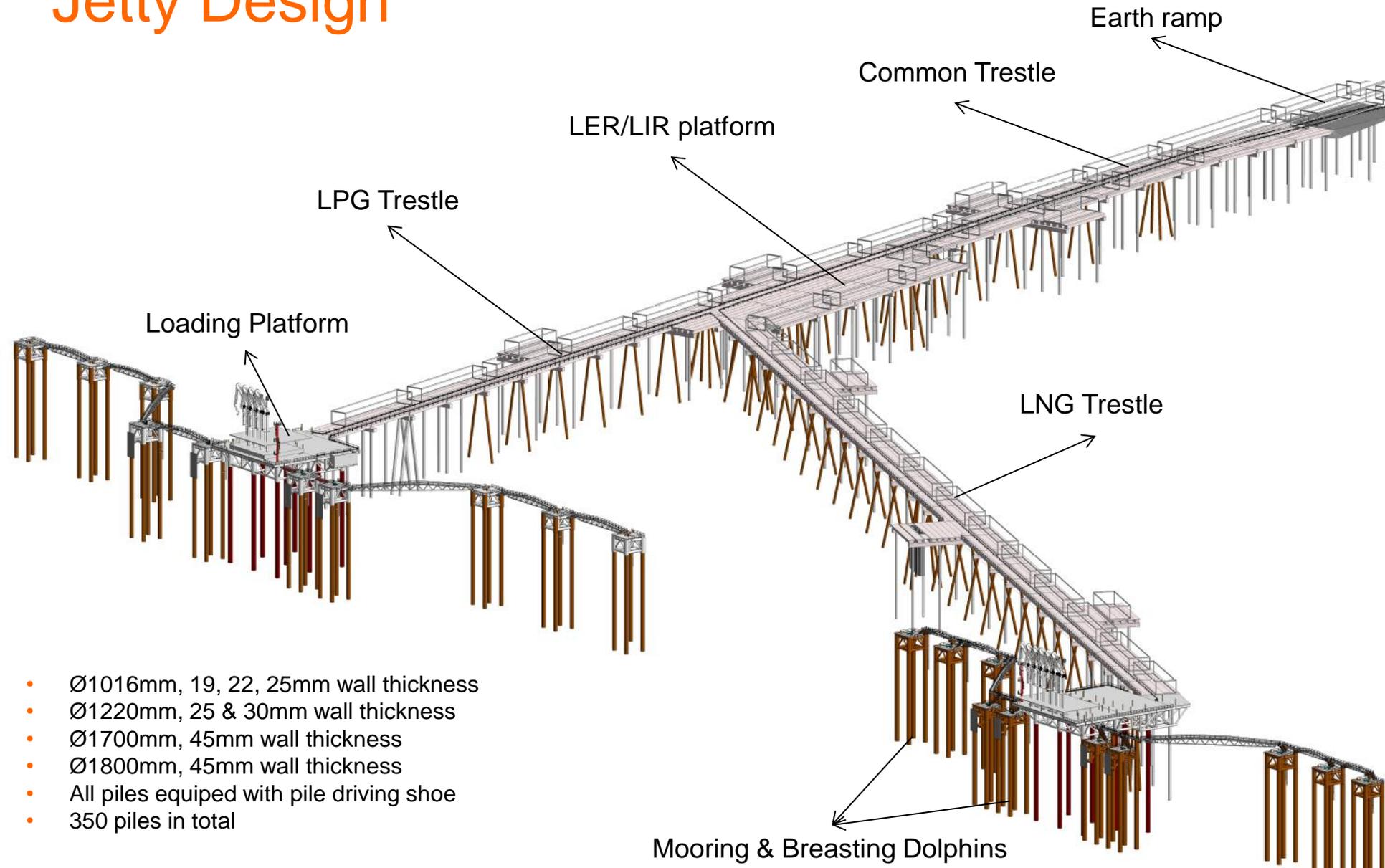


Design MOF



- Temporary structure
- Cellular cofferdam (alternative for piled deck)
- Removal of soft materials
- Monopile mooring & breasting dolphins

Jetty Design



- Ø1016mm, 19, 22, 25mm wall thickness
- Ø1220mm, 25 & 30mm wall thickness
- Ø1700mm, 45mm wall thickness
- Ø1800mm, 45mm wall thickness
- All piles equipped with pile driving shoe
- 350 piles in total

Geotechnical Design

AS 2159-2009 Piling – Design and Installation

- Risk assessment to determine basic geotechnical strength reduction factor
- Site, Design, Installation are key factors

TABLE 4.3.2(A)
WEIGHTING FACTORS AND INDIVIDUAL RISK RATINGS
FOR RISK FACTORS

Risk factor	Weighting factor (w_i)	Typical description of risk circumstances for individual risk rating (IRR)		
		1 (Very low risk)	3 (Moderate)	5 (Very high risk)
Site				
Geological complexity of site	2	Horizontal strata, well-defined soil and rock characteristics	Some variability over site, but without abrupt changes in stratigraphy	Highly variable profile or presence of karstic features or steeply dipping rock levels or faults present on site, or combinations of these
Extent of ground investigation	2	Extensive drilling investigation covering whole site to an adequate depth	Some boreholes extending at least 5 pile diameters below the base of the proposed pile foundation level	Very limited investigation with few shallow boreholes
Amount and quality of geotechnical data	2	Detailed information on strength compressibility of the main strata	CPT probes over full depth of proposed piles or boreholes confirming rock as proposed founding level for piles	Limited amount of simple in situ testing (e.g., SPT) or index tests only
Design				
Experience with similar foundations in similar geological conditions	1	Extensive	Limited	None

IRR	w_i	$w_i * IRR$	ARR
5	2	10	
3	2	6	
1	2	2	
3	1	3	

Geotechnical Design

Pile testing improves strength reduction factor -> 15% piles dynamic testing

TABLE 4.3.2(C)
BASIC GEOTECHNICAL STRENGTH REDUCTION FACTOR (ϕ_{gb})
FOR AVERAGE RISK RATING

Range of average risk rating (ARR)	Overall risk category	ϕ_{gb} for low redundancy systems	ϕ_{gb} for high redundancy systems
ARR ≤ 1.5	Very low	0.67	0.76
1.5 < ARR ≤ 2.0	Very low to low	0.61	0.70
2.0 < ARR ≤ 2.5	Low	0.56	0.64
2.5 < ARR ≤ 3.0	Low to moderate	0.52	0.60
3.0 < ARR ≤ 3.5	Moderate	0.48	0.56
3.5 < ARR ≤ 4.0	Moderate to high	0.45	0.53
4.0 < ARR ≤ 4.5	High	0.42	0.50
>4.5	Very high	0.40	0.47

2,0 \leq	ARR	\leq 2,5
$\phi_{gb,low red}$	=	0.56
$\phi_{gb,high red}$	=	0.64

$$\phi_g = \phi_{gb} + (\phi_{gt} - \phi_{gb}) * K \geq \phi_{gb}$$

ϕ_{gt} = intrinsic test factor =

0.8 (for dynamic load testing of performed piles)

K = testing benefit factor = $1,13^p / (p+3,3) \leq 1$ for dynamic load testing

p = percentage of total piles that are tested and meet the specified acceptance criteria

p = 15 % PDA on working piles

K = 0.92623

$$\phi_{g,low red} = 0.78$$

$$\phi_{g,high red} = 0.79$$

$$\phi_{g,compress} = 0.78$$

$$\phi_{g,tension} = 0.62 \text{ (allowing a 20% reduction for tension)}$$

Geotechnical Design

Vertical Loaded Piles

- Overburden: API RP2A WSD (2010) skin friction & end bearing
- Rock: based on rock strength: % UCS, with lower and upper limit
- Axial pile reaction (T-z, Q-z): API
- Point of Virtual Fixity: Tomlinson 1.4R for OC clays and rock
1.8T for NC clays and granular soils
R, T = Stiffness factor depending on pile stiffness and subsoil modulus
- Correlation between I_s50 (point load) and UCS (unconfined compressive strength)

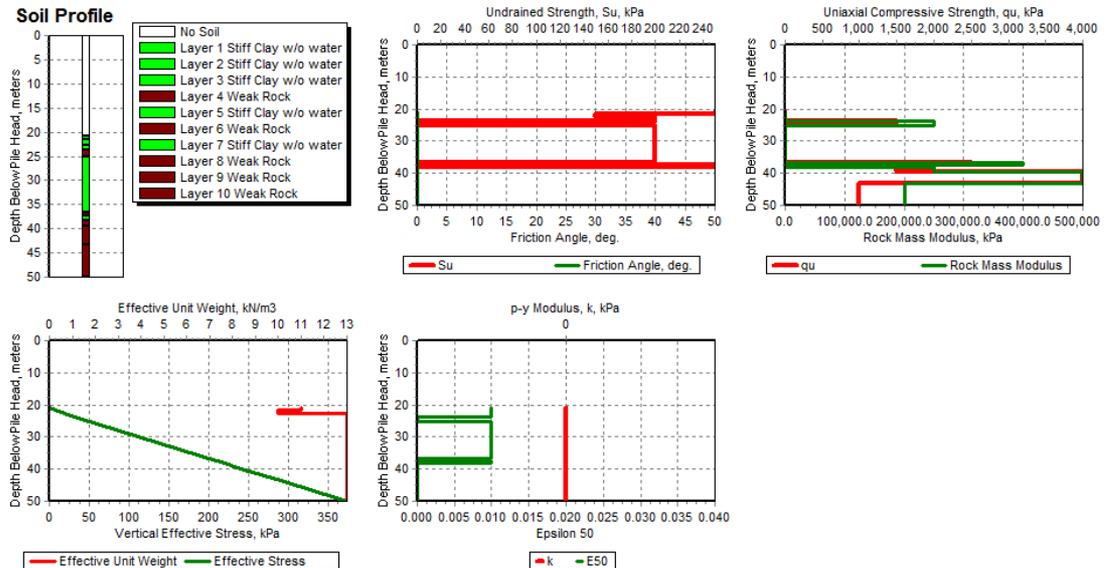
Sub unit	Axial Point Load Test	Diametral Point Load Test
	Mean Value	Mean Value
3aii	16.0	15.2
3aiii	16.5	14.5

Geotechnical Design

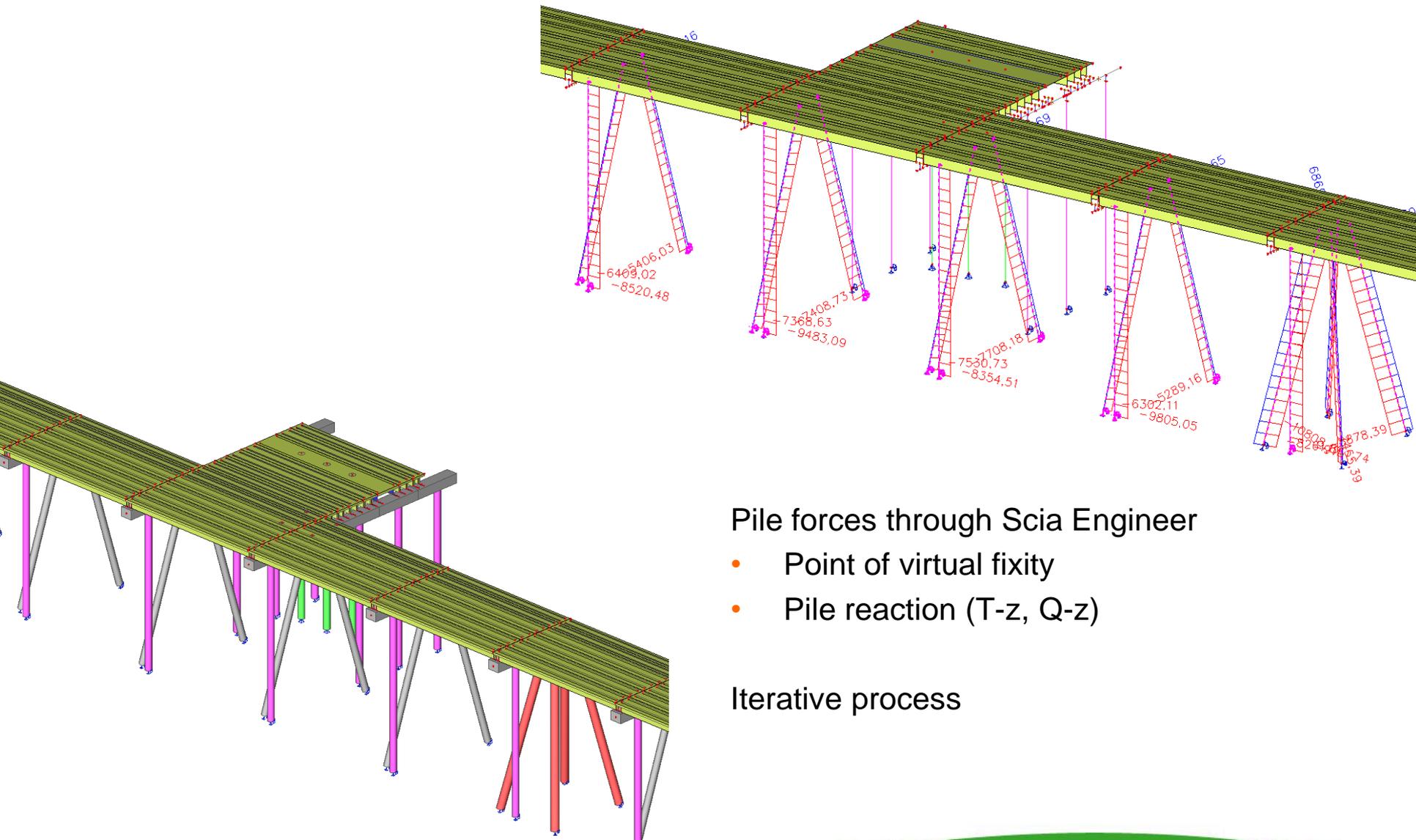
Laterally Loaded Piles

- Soil: API RP2A WSD (2010)
- Rock: Cemented Soil (Evans & Duncan). Parameters through Hoek-Brown Weak Rock model (Reese). Input parameters: Effective weight, UCS, Young's modulus, RQD
- Geotechnical reduction factor applied directly to p-y for geot. capacity, for energy adsorption other way around.
- Point of virtual fixity determined by matching deformations and bending moments with structural model (SCIA).

Software: Lpile 2012 (Ensoft)
RocLab



Geotechnical Design



Pile forces through Scia Engineer

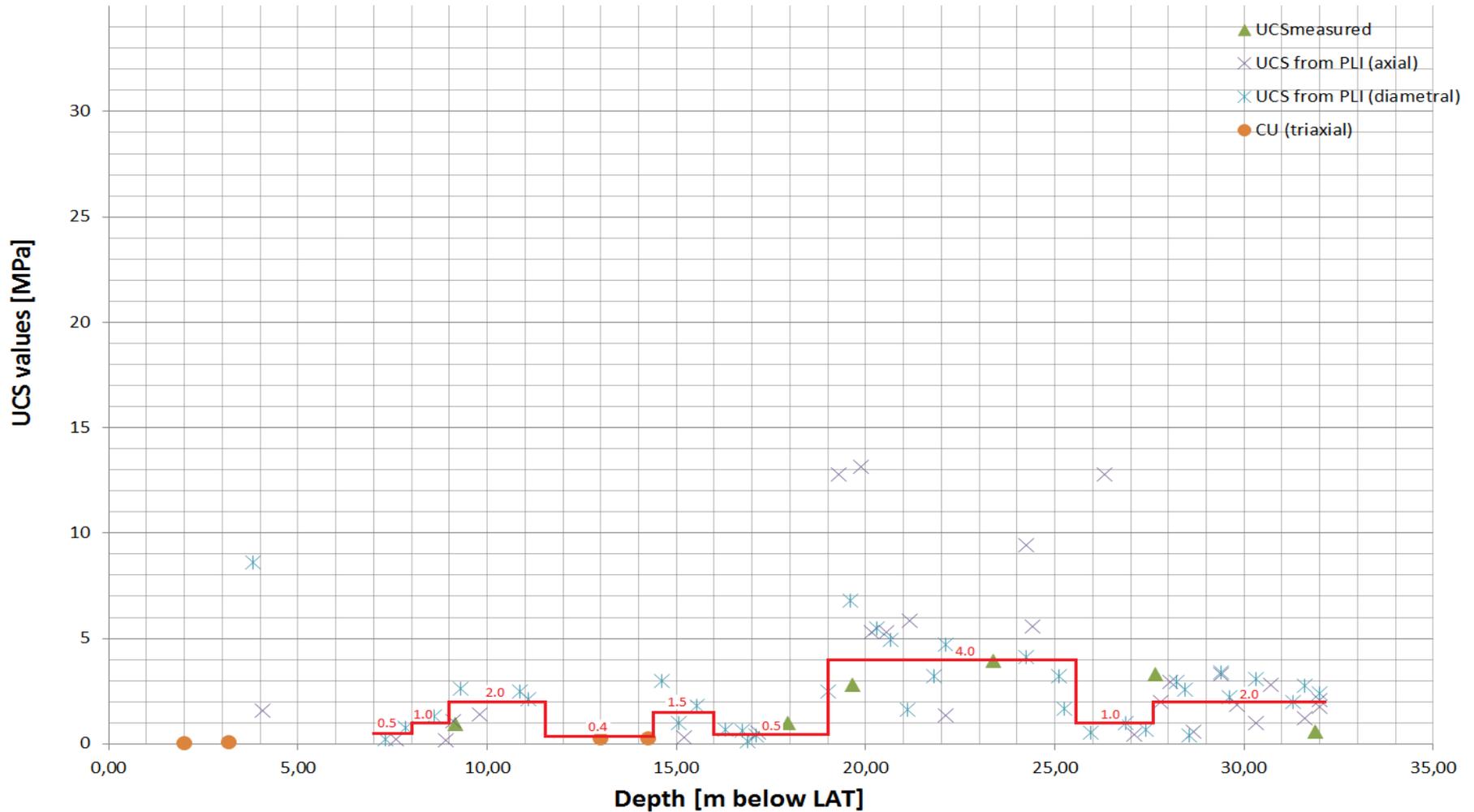
- Point of virtual fixity
- Pile reaction (T-z, Q-z)

Iterative process

Variability

Design UCS Profile

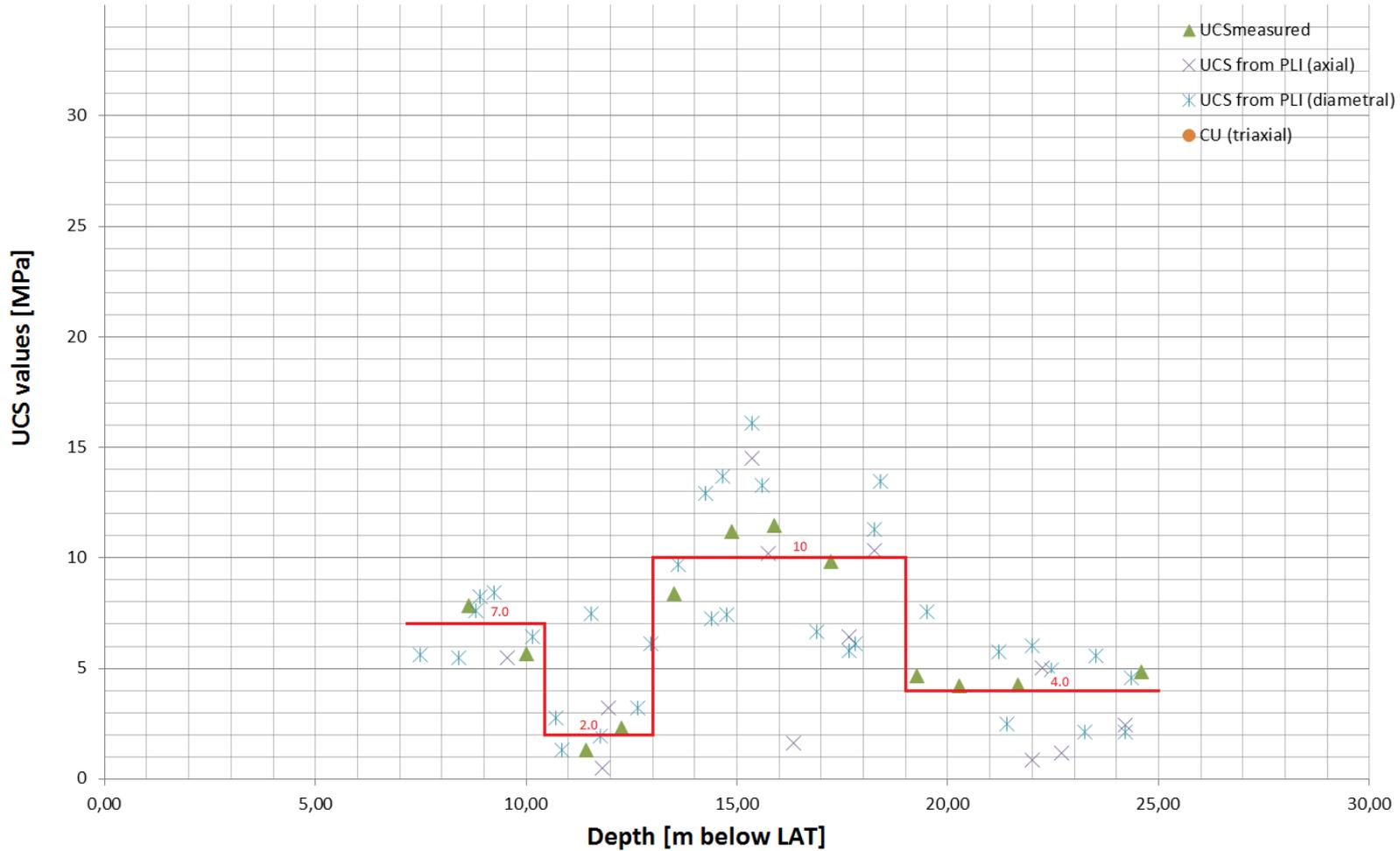
PLJ-21



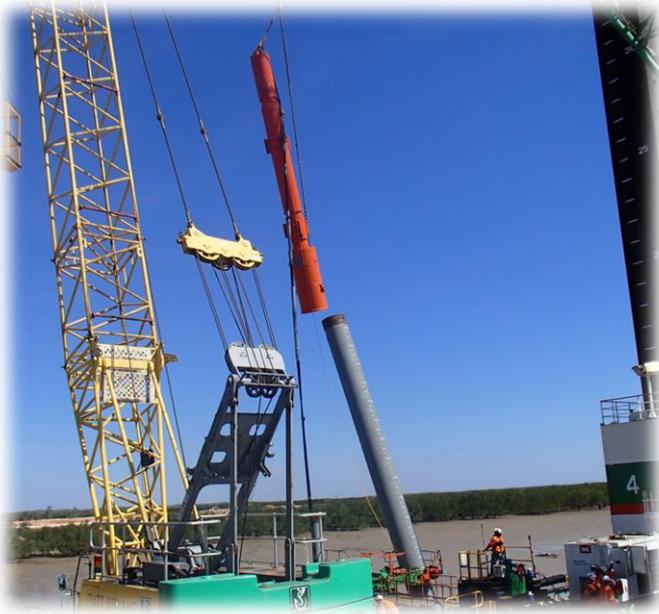
Variability

Design UCS Profile 25m away

PLJ-12



Pile Driveability



Qualitative

- Borehole description
- Core photos
- Site visit during soil investigation
- Local experience

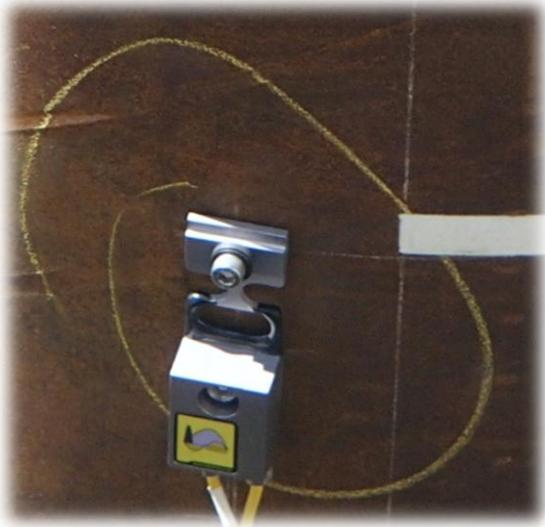
Quantitative

- GRLWEAP / PDPwave (Profound)
- Build expected and upperbound scenarios
- Pile driveability test

Anticipated hammers

IHC S200, S280, S500 hydrohammers

Pile Load Testing



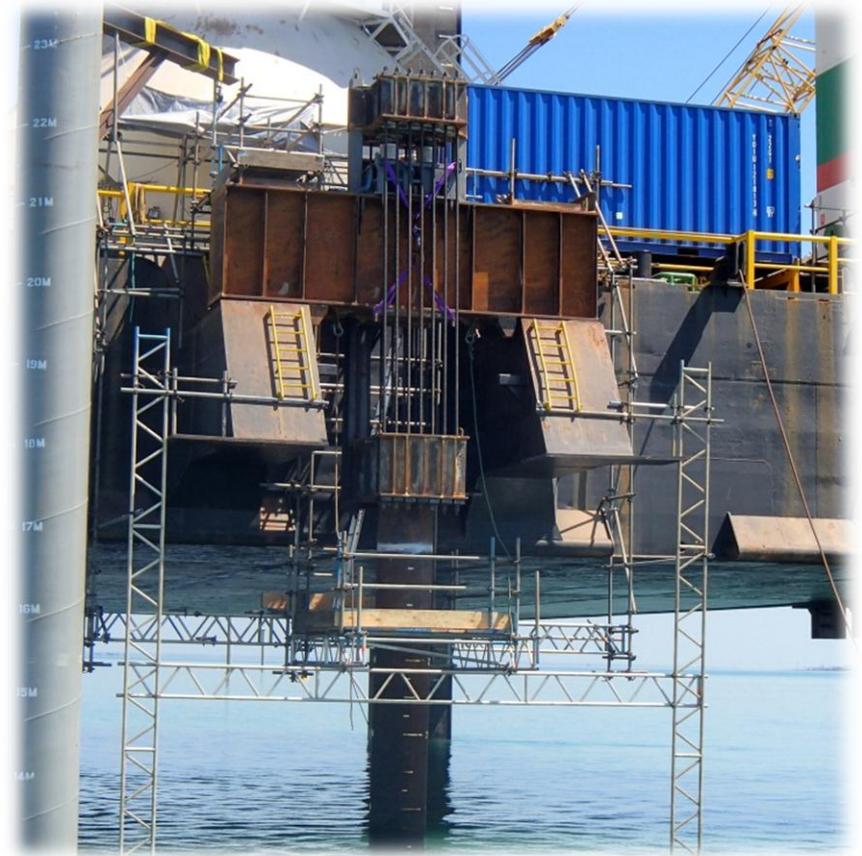
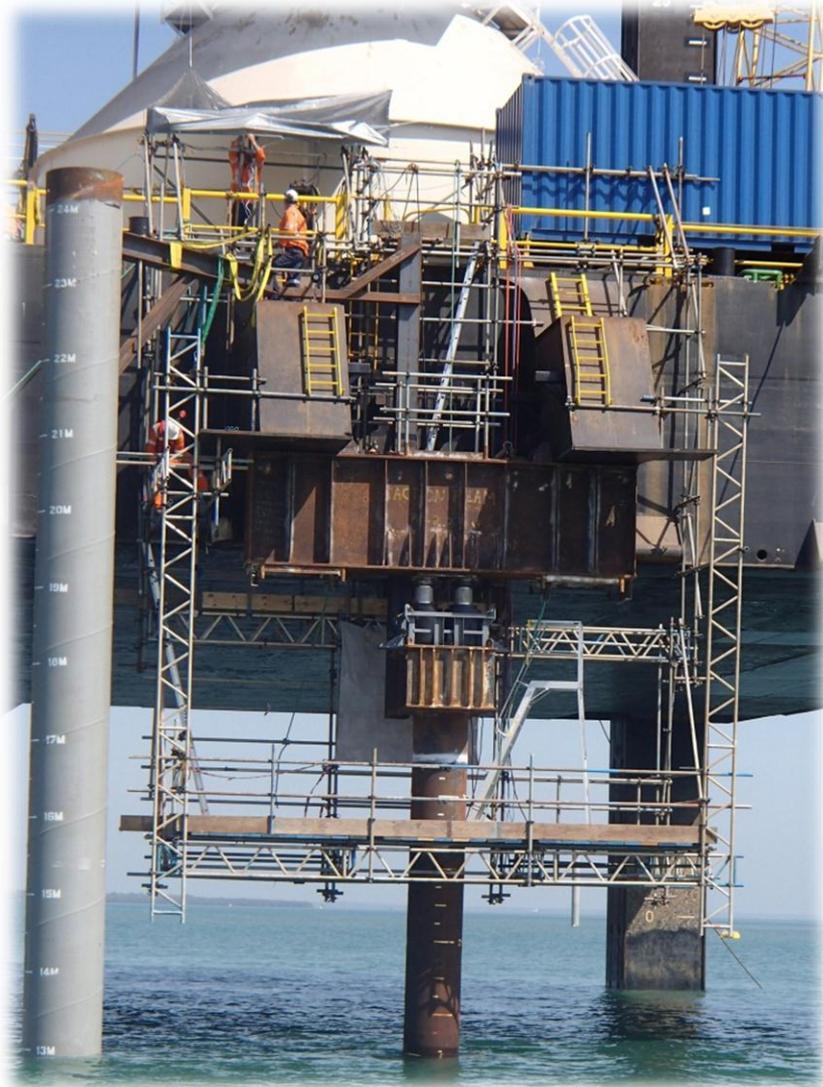
Test pile program

- PDA (EOID) 13-07-2013
- DLT (SORD-1) 16-07-2013
- DLT (SORD-2) 29-07-2013
- SLT Compression 11-08-2013
- SLT Tension 14-08-2013

Used as design verification and calibration of PDA/DLT

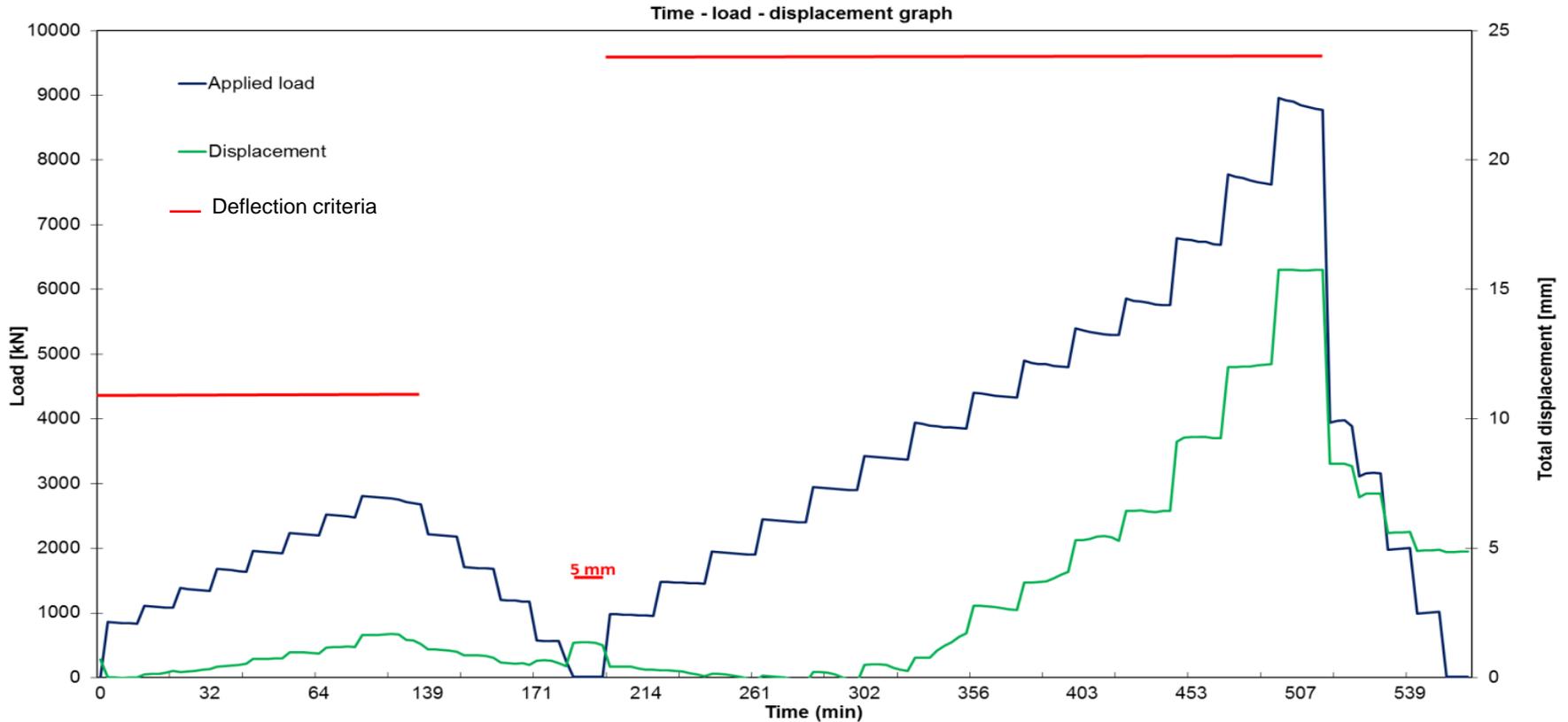


Pile Load Testing



- Ø762mm pile
- At exact borehole location
- 7m into rock
- Jack-up barge with test nose
 - 12500kN compression test capacity
 - 9000kN tension test capacity

Pile Load Testing



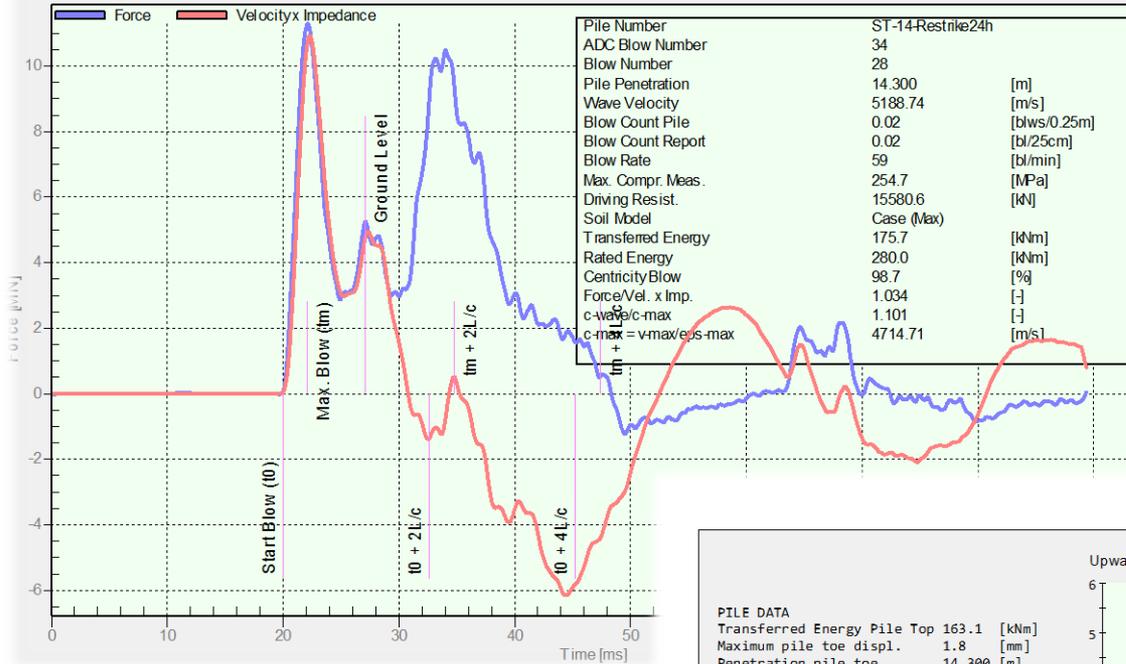
	compression	Tension
	[kN]	[kN]
Design Capacity (P_g)	4644	3732
PDA Capacity (End Of Initial Drive EOID)	10748	4542
Dynamic Load Test (DLT) Capacity (Re-strike SORD-2)	17276	9332
Static Load Test (SLT) Capacity	>12000	>9000

- DLT results conservative
- Set-up
- Compression + tension capacity >> calculated.

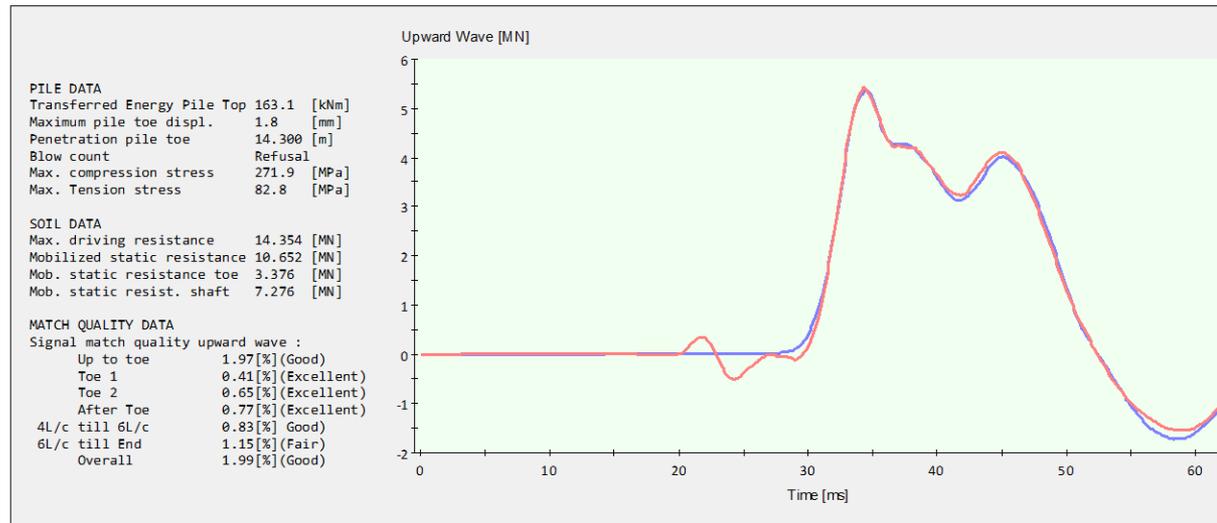
Pile Load Testing

TP14 - SORD-1

Force and Velocity x Impedance (Blow Number: 28)



TP14 - SORD-1



— Calculated
— Measured

Upward travelling wave as function of Time at level = 0.000

In Practice

- Pile capacities far exceeding design
- Highly variable driving conditions
- Early refusals, also in weak material already apparent after test driving
- No pile driving at night
- Limitations on allowable driving energy

Fall Back Scenarios

- Prove sufficient capacity with PDA/DLT
- Drill out to design toe level and redrive
- Drill out and install rock anchor
 - Shear keys installed during fabrication
 - Reinforcement designed and rebars ready on site



Cantilever Bridge (CLB)



Cantilever Bridge

Cantilever Bridge



Questions?

