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Foundation Design for the Beatrice Offshore Wind Farm

R. McLean – SUPERGEN Wind Hub General Assembly, 08th November 2018

Contents

Introduction

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Overview

588MW offshore wind farm in the Moray Firth

Clean electricity for 450,000 homes

Overall project £2.6bn

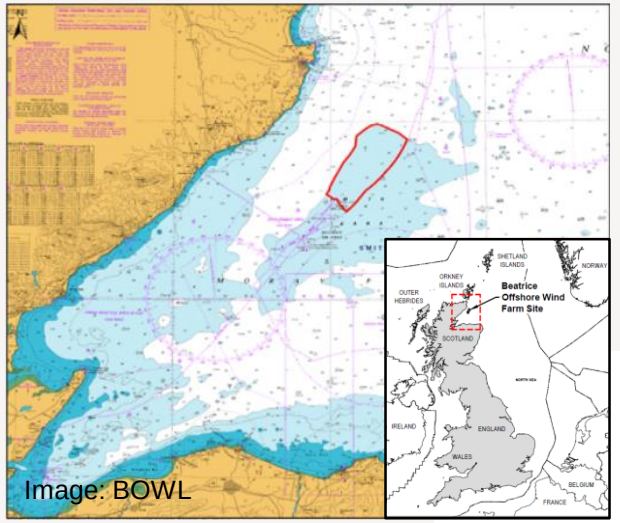
Site:

Circa 13km offshore

132km^2

Water depths 35-55m LAT

Scotland's largest offshore wind farm!



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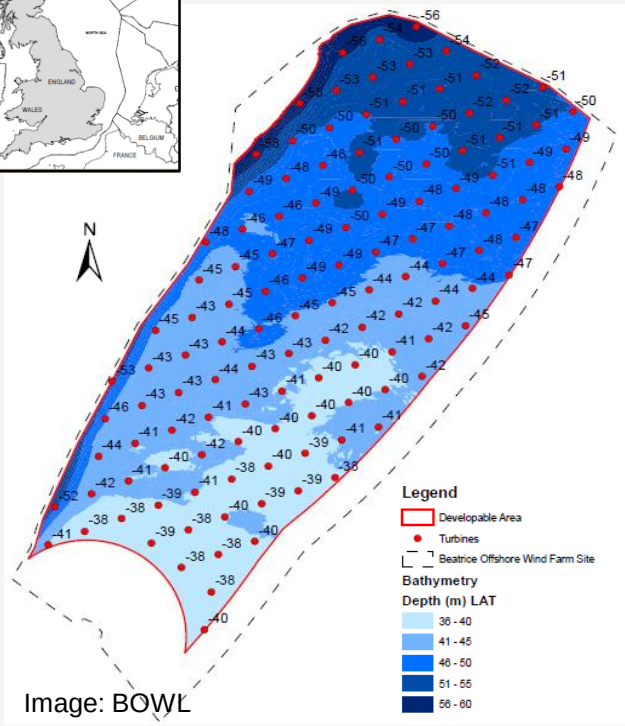


Image: BOWL

Overview

Offshore structures

84no. 7MW wind turbine generators (WTGs)

2no. offshore transformer modules (OTMs)

Foundations = jackets on driven piles

86 jackets; 85,000 tonnes

344 piles; >14km total length; 44,000 tonnes

Deepest offshore wind fixed structures in the world


Image: BOWL

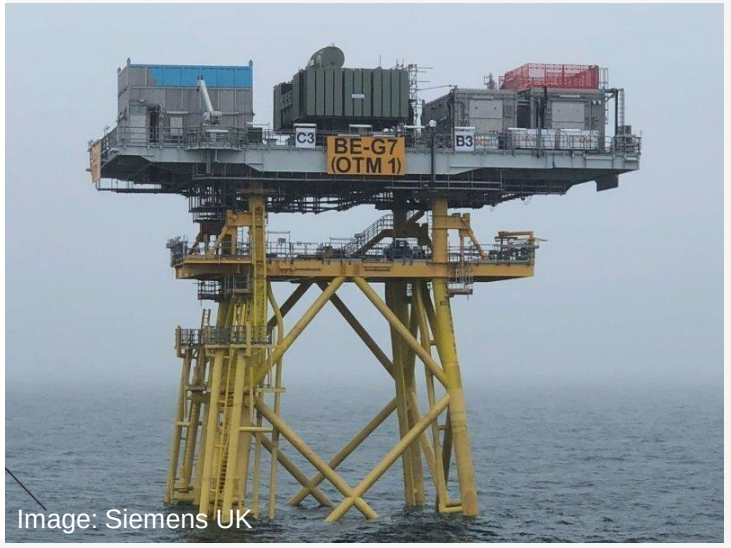
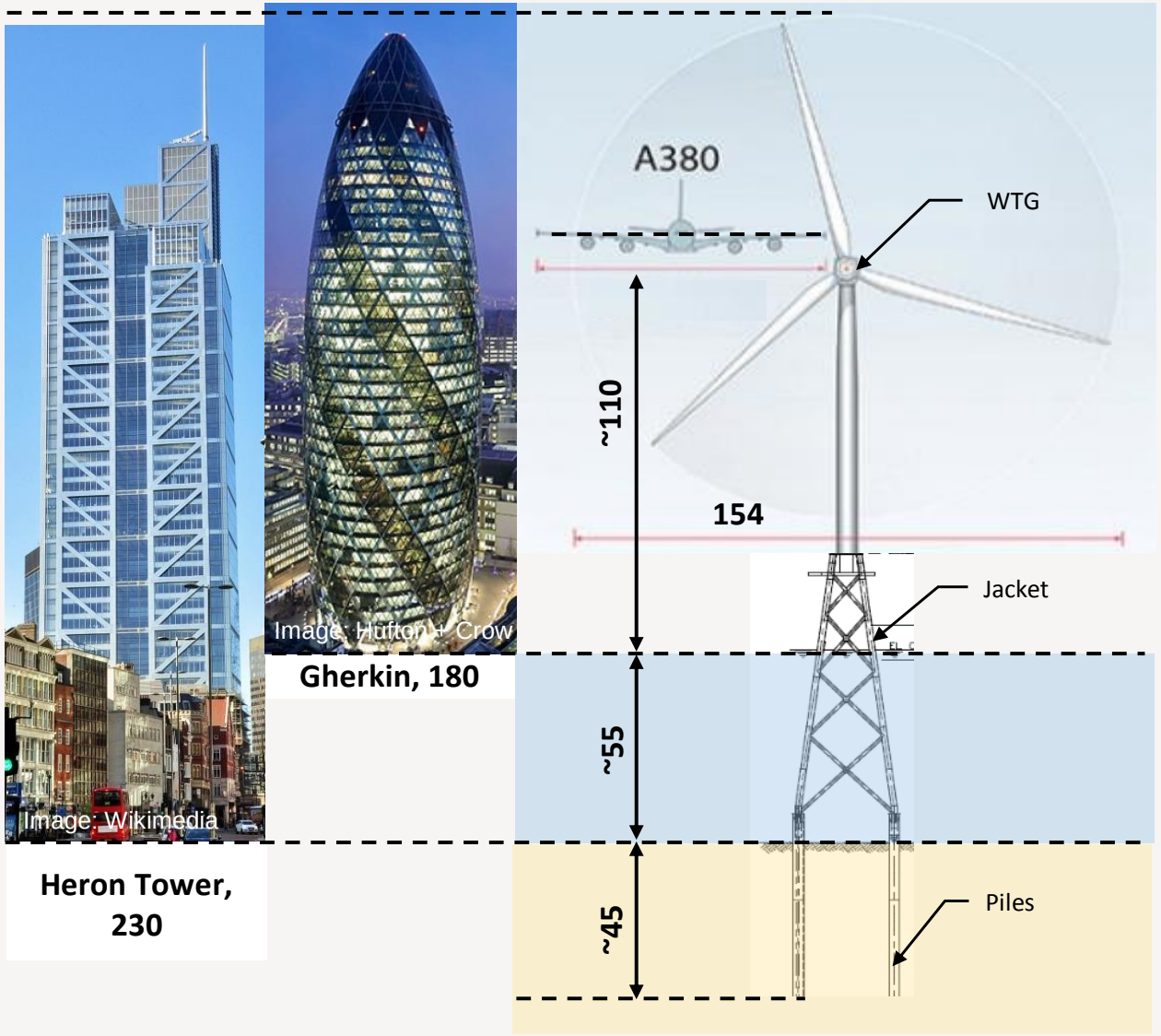


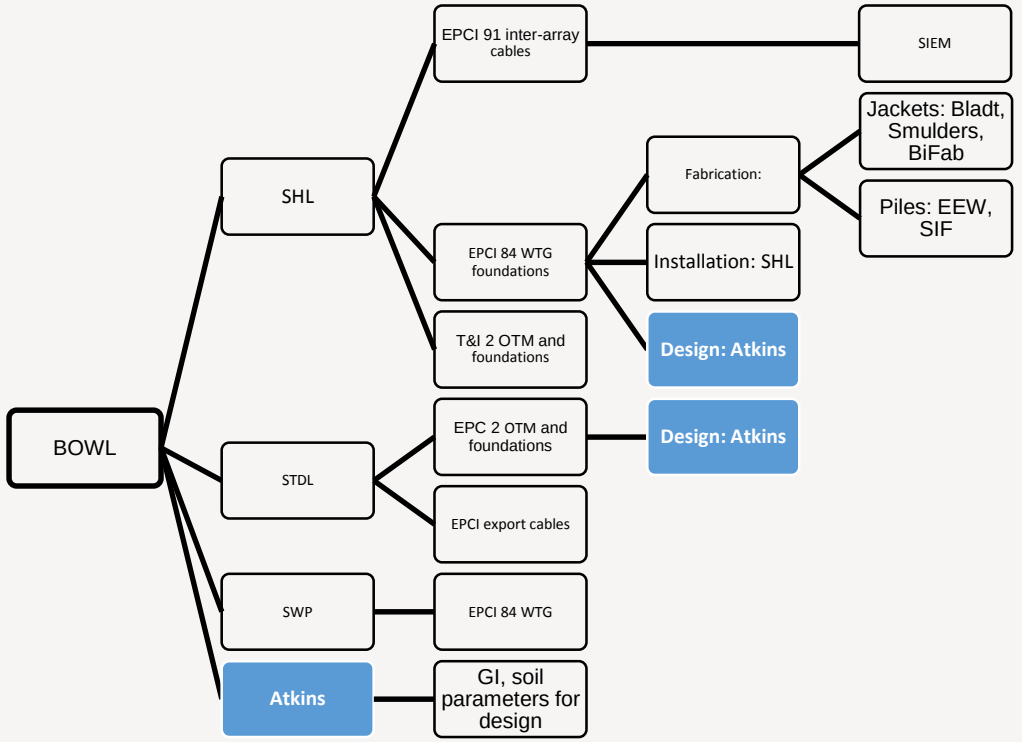
Image: Siemens UK

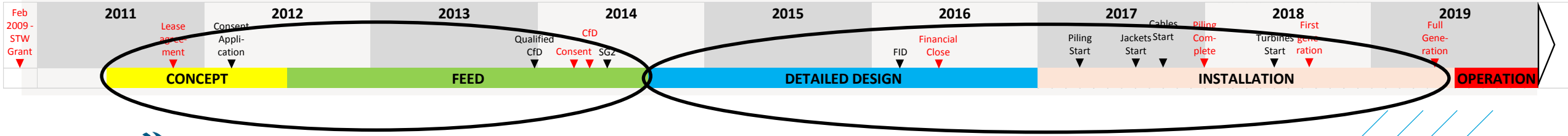

A380
WTG
~110
154
Jacket
~55
~45
Piles
Image: Hufton + Crow
Gherkin, 180
Image: Wikimedia
Heron Tower, 230

SSE Offshore Wind Alliance

Framework of key suppliers designed to address the key challenges of Round 3 offshore wind and drive efficiencies in SSE's offshore wind programme.

Collaborative work through Concept and FEED between Developer, WTG and OSP Supplier, Installation contractor, Fabricator and Designer.





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Foundation Design Challenges

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Site Characterisation

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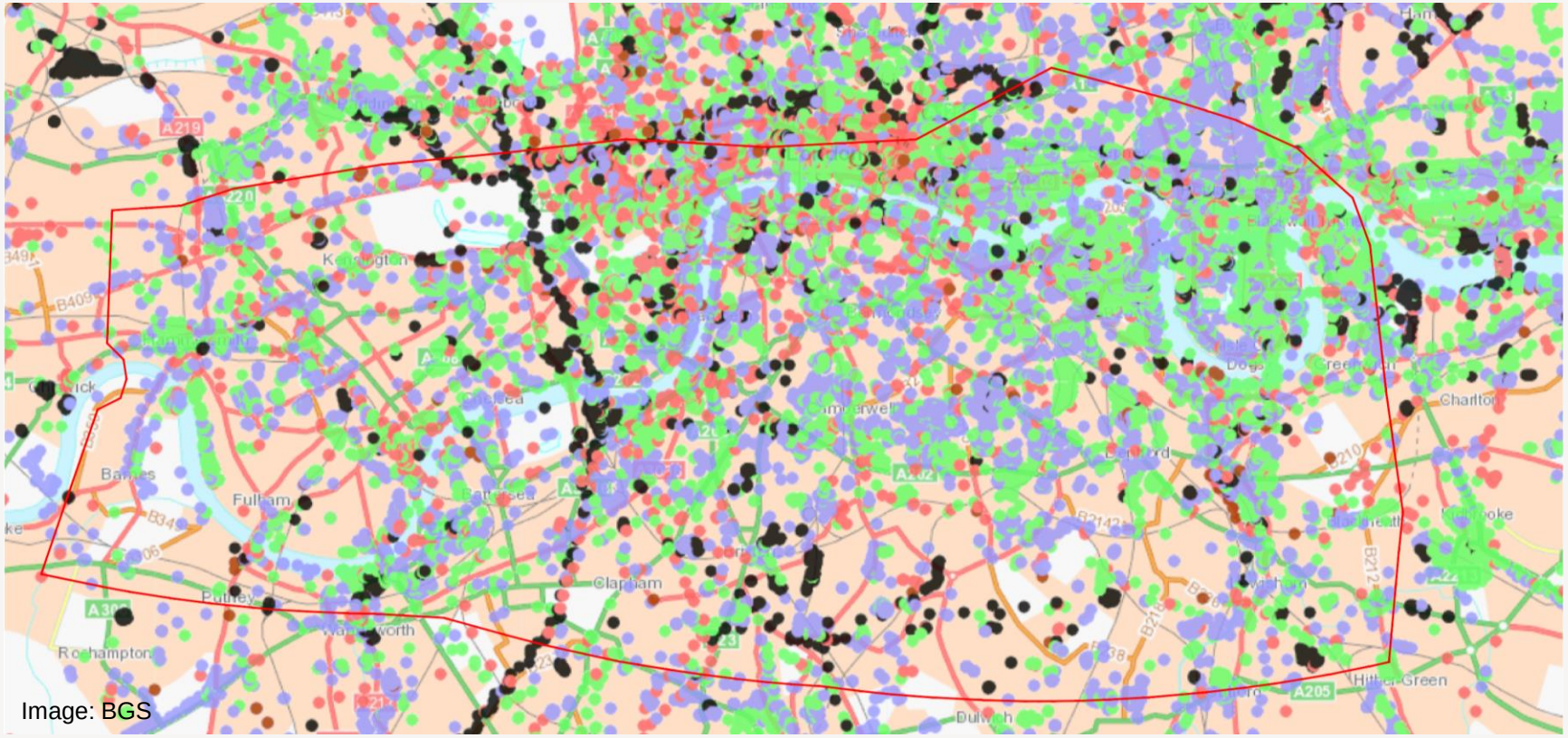
Vast site

Available data - onshore



Available data - offshore

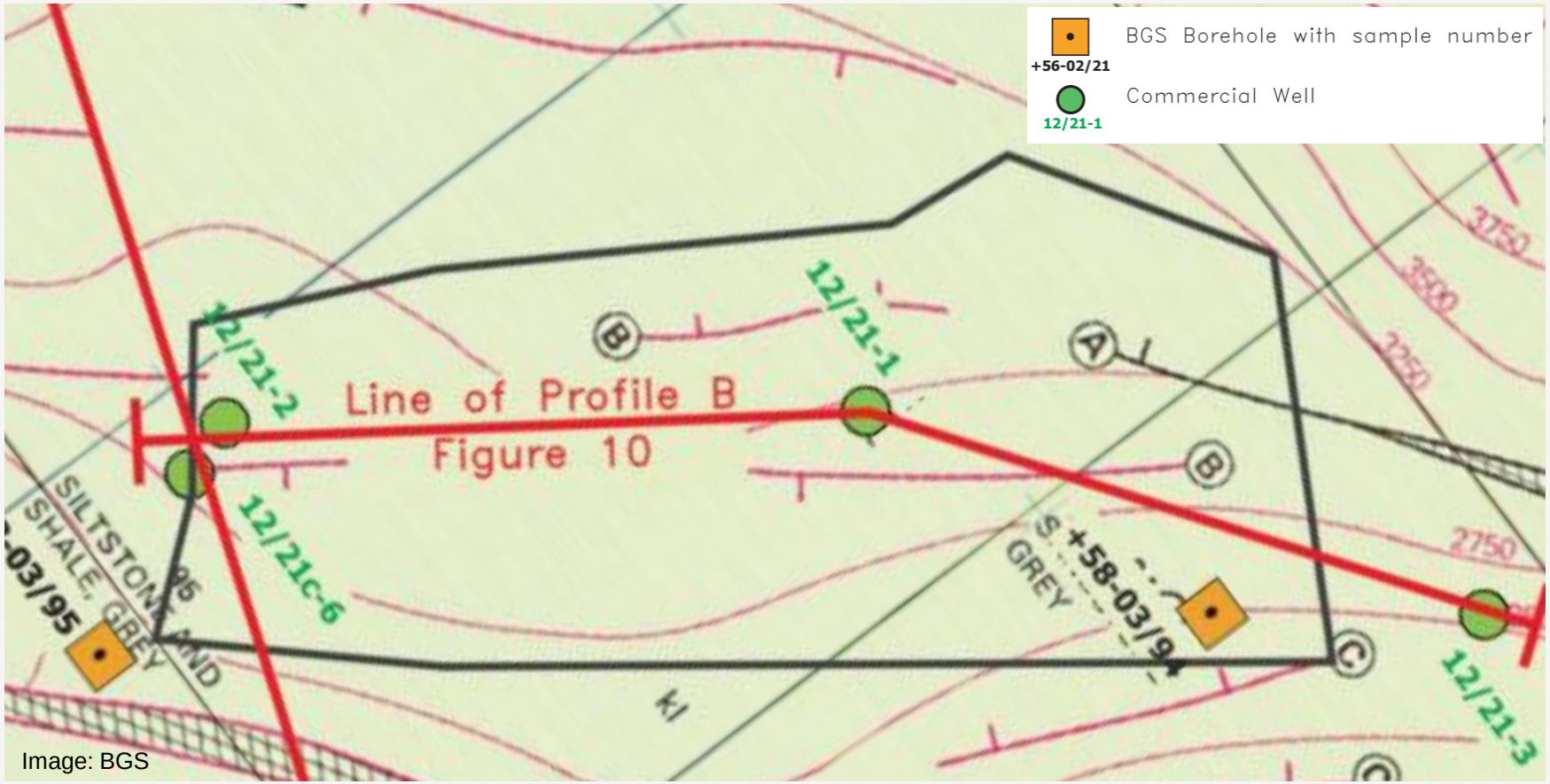
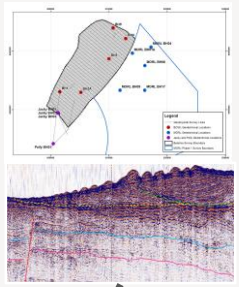


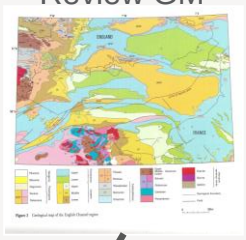
Image: BGS

Phased investigation

Geophys, 5 BH
Prelim GM

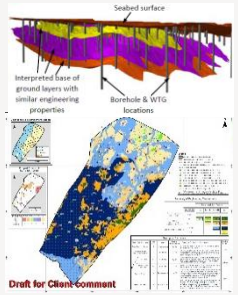


Desk study
Review GM

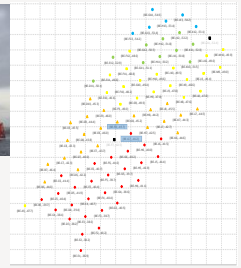


Interim GI

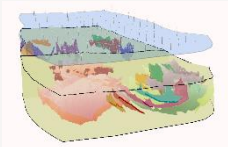
Update GM

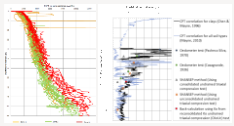


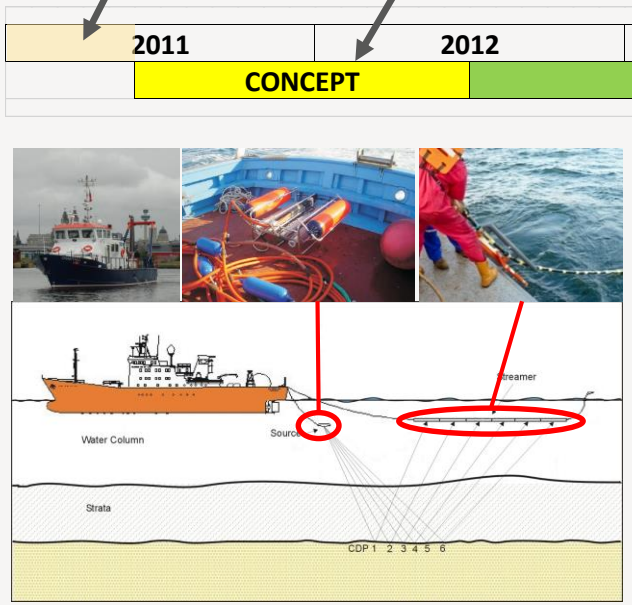
Completion GI

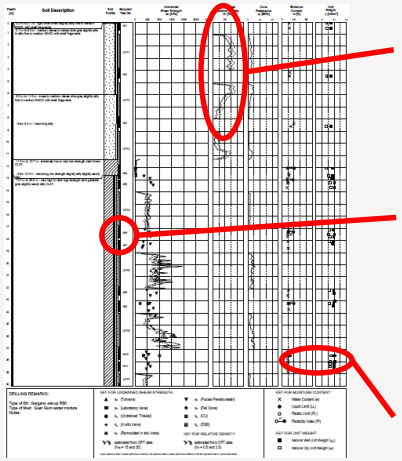


Final GM









CPT

Sampling

Lab tests

Routine

Advanced

Images: BOWL/ Fugro/ Atkins

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Pile Design Process

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Loading

Relatively small vertical load

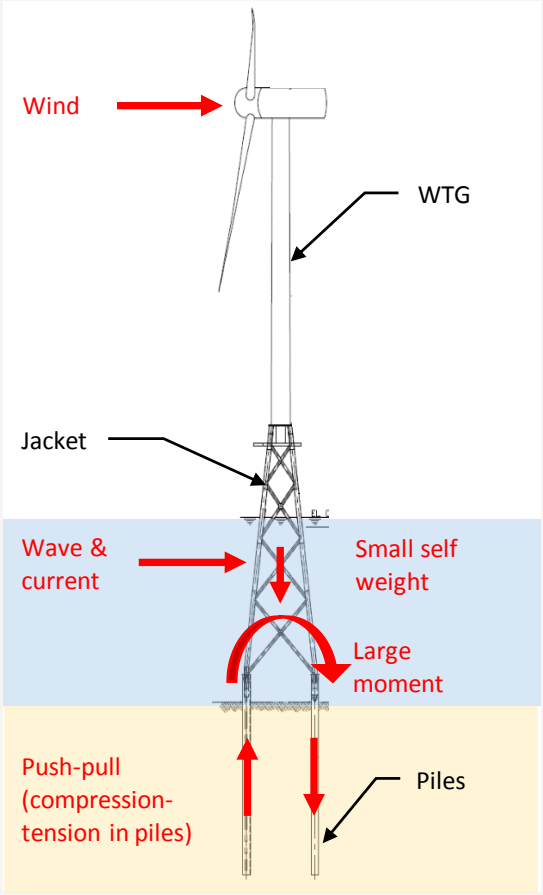
Large horizontal loads from wind, waves and currents

High overturning moment at mudline

Resisted by piles in ‘push / pull’

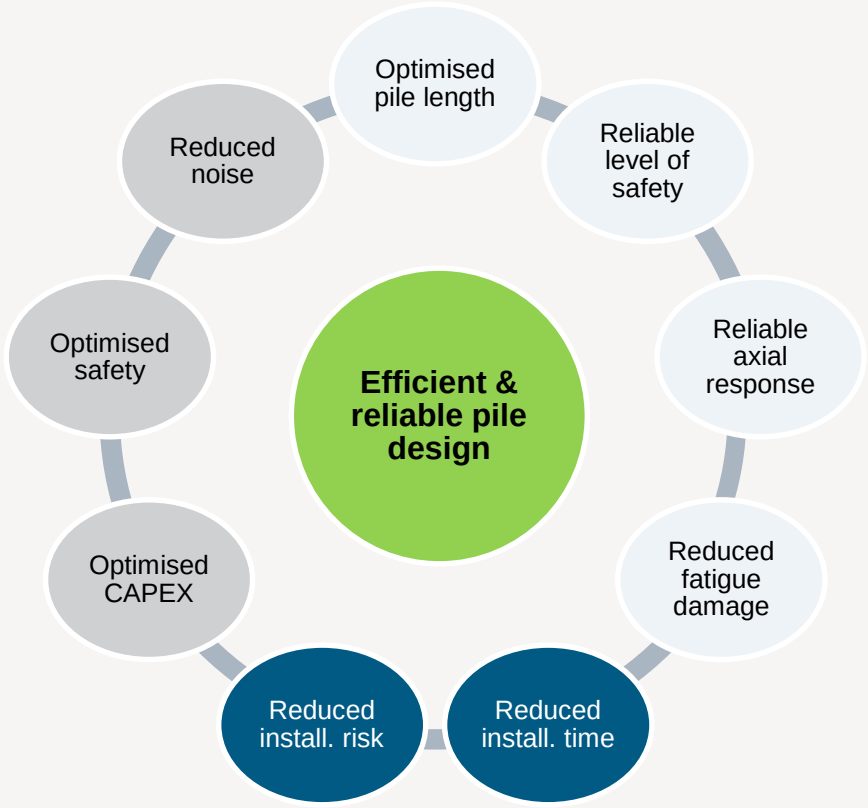
Piles work in compression & tension

Cyclic

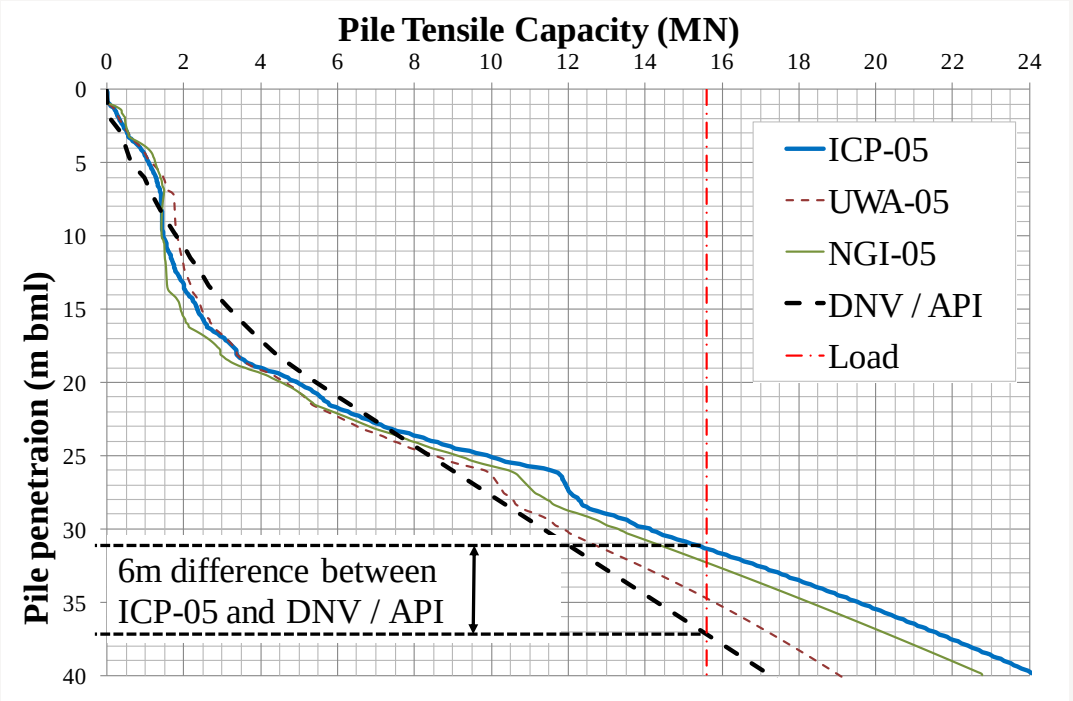


Pile axial capacity

Need efficiency & reliability



Which method?



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Jacket Design Process

- Clustering approach
- Structural analyses

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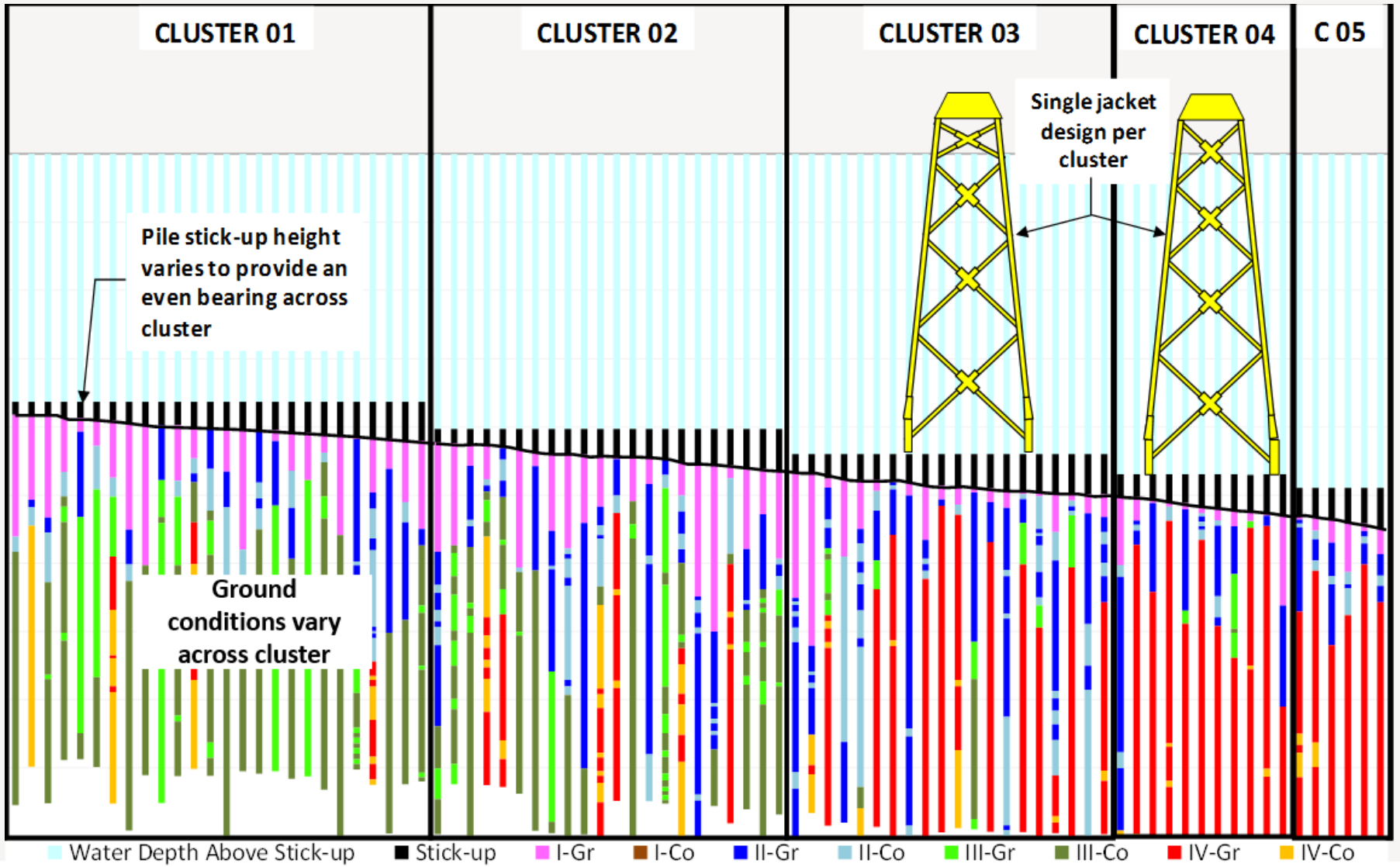

CLUSTER 01
CLUSTER 02
CLUSTER 03
CLUSTER 04
C 05
Single jacket design per cluster
Pile stick-up height varies to provide an even bearing across cluster
Ground conditions vary across cluster
Water Depth Above Stick-up
Stick-up
I-Gr
I-Co
II-Gr
II-Co
III-Gr
III-Co
IV-Gr
IV-Co

Design Process

Coupled Analysis

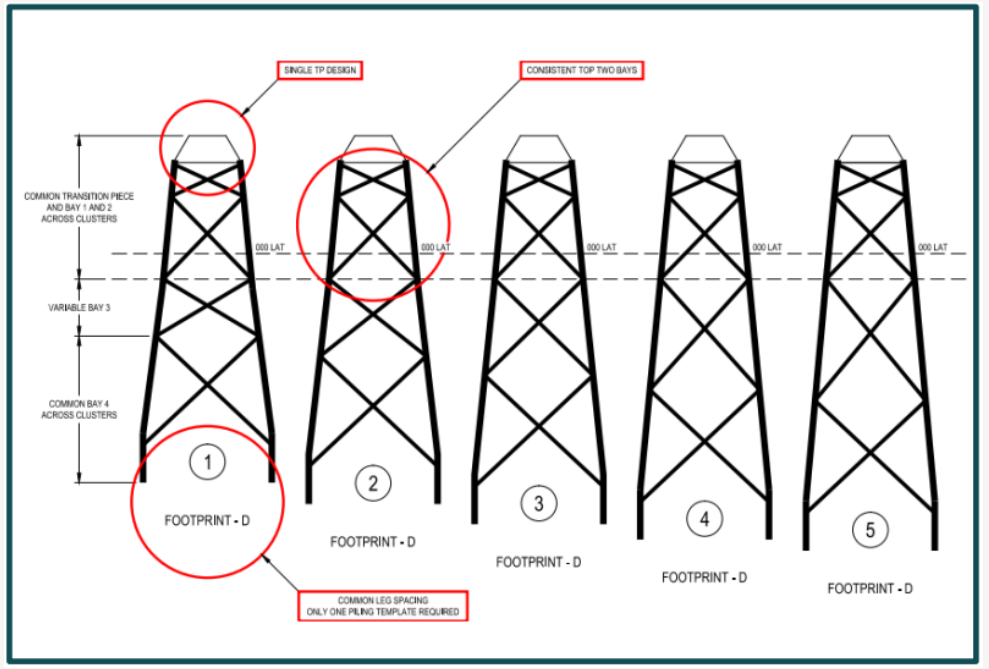
Bookending Site

Uncoupled Analysis

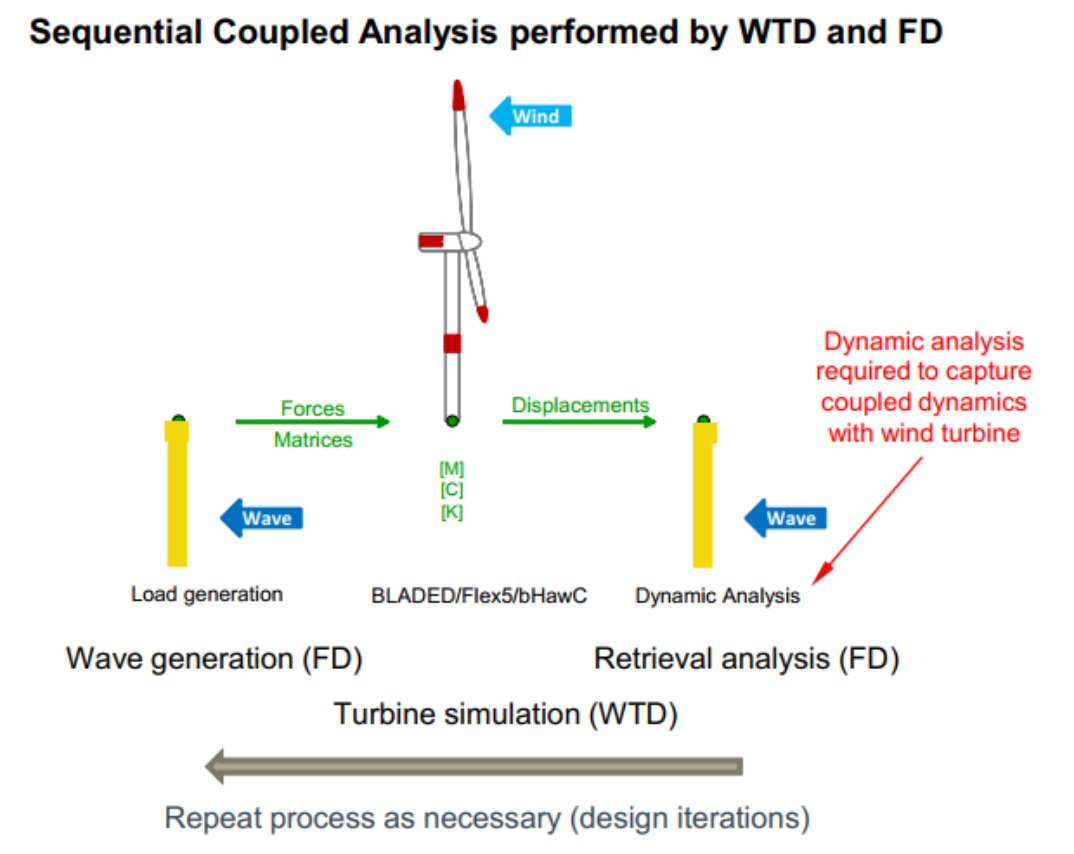
Variances in-Cluster

AFC Design

Inclusive of all contributors



Design Process: Coupled Analysis



Pre-processing:

› ~1,000 wave loading simulations

SWP Analysis:

› Up to 20,000 combined wave + turbine simulations

Post-processing (Retrieval):

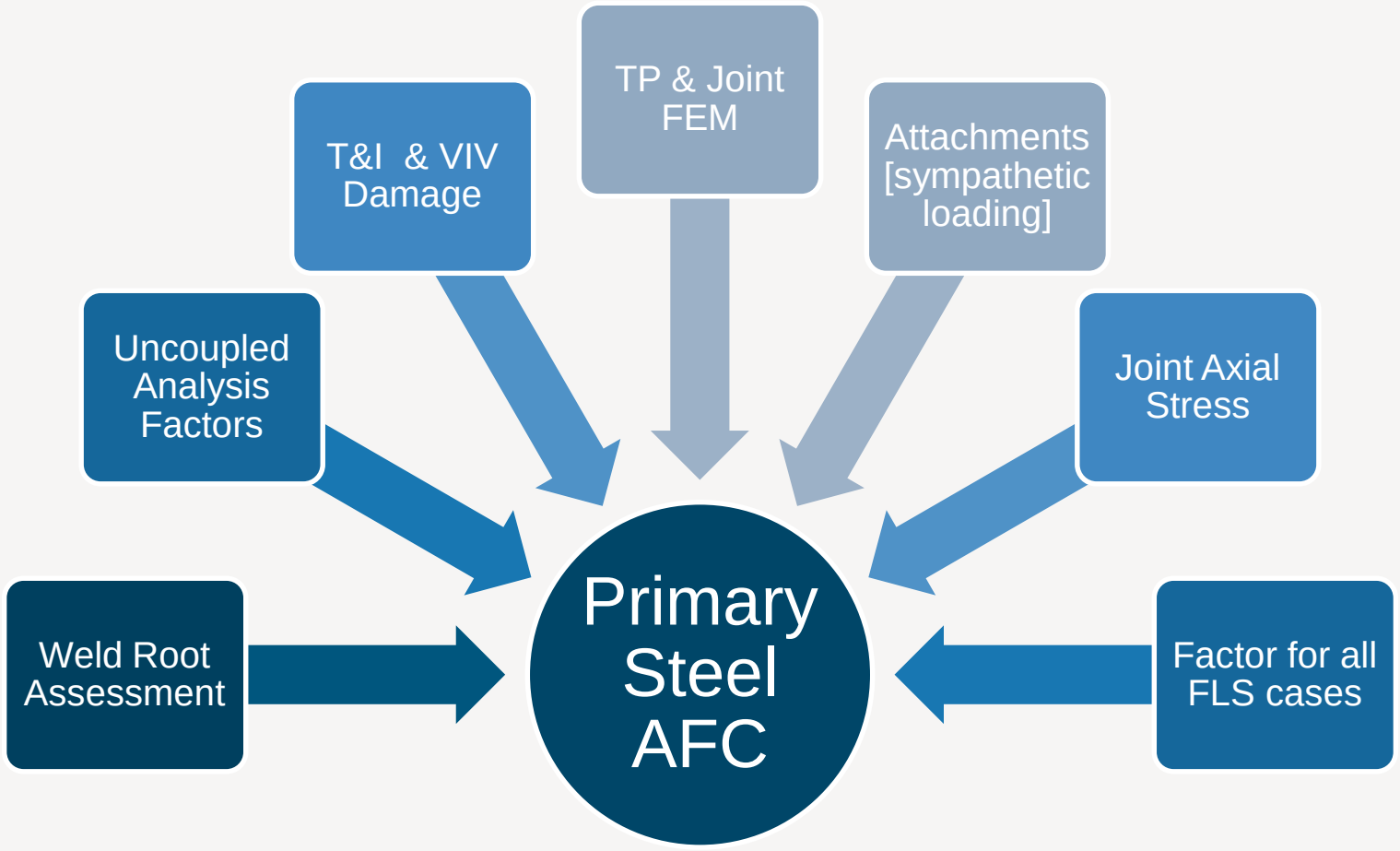
› ~300 critical ULS simulations

› 232 FLS simulations

› Code checking

Design Process: Uncoupled Analysis

Design Process: AFC Design



Fabrication

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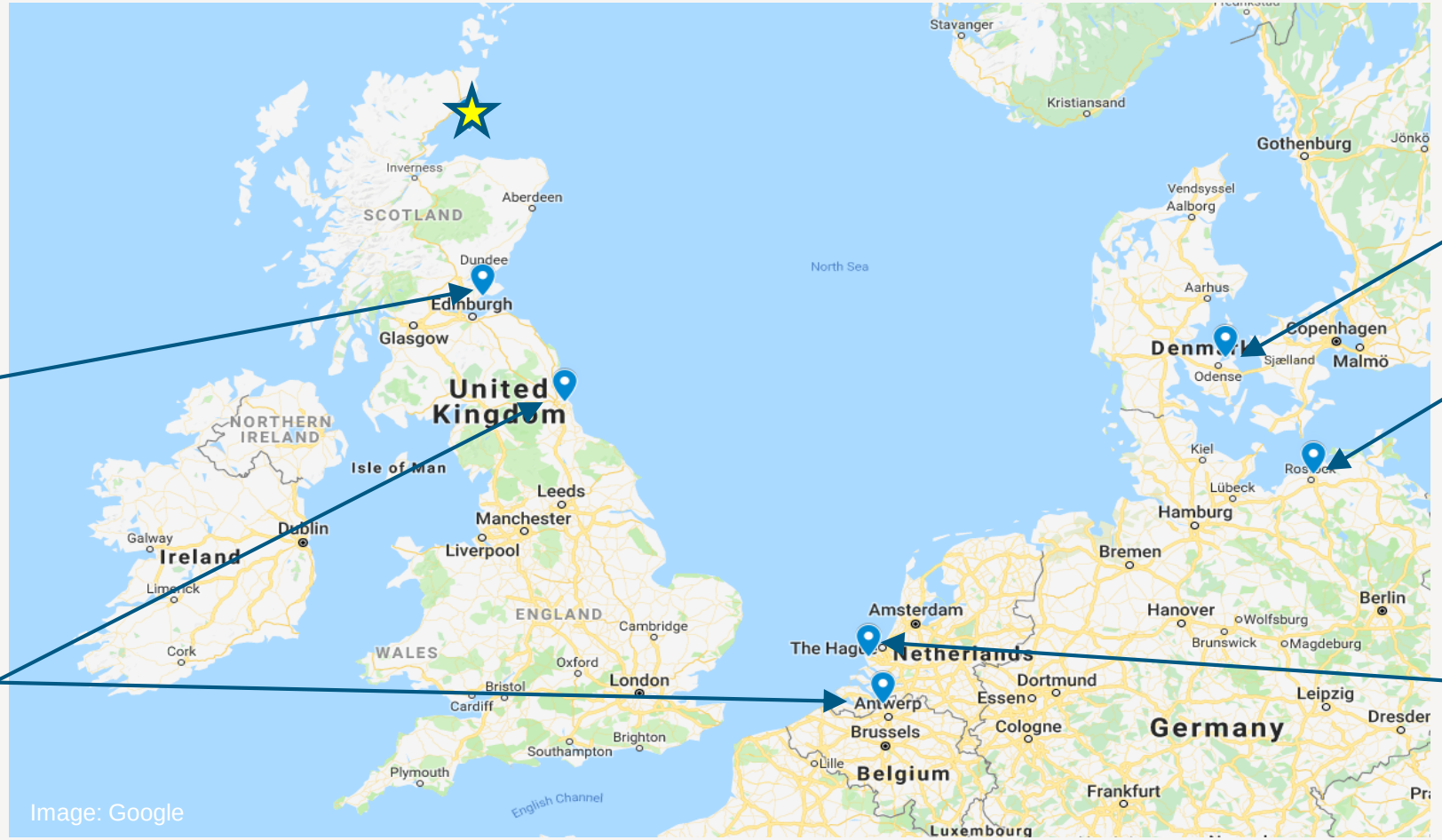
Beatrice Foundation Fabricators



FAB

BLADT INDUSTRIES

EIFFAGE SMULDERS

EEW

Sif

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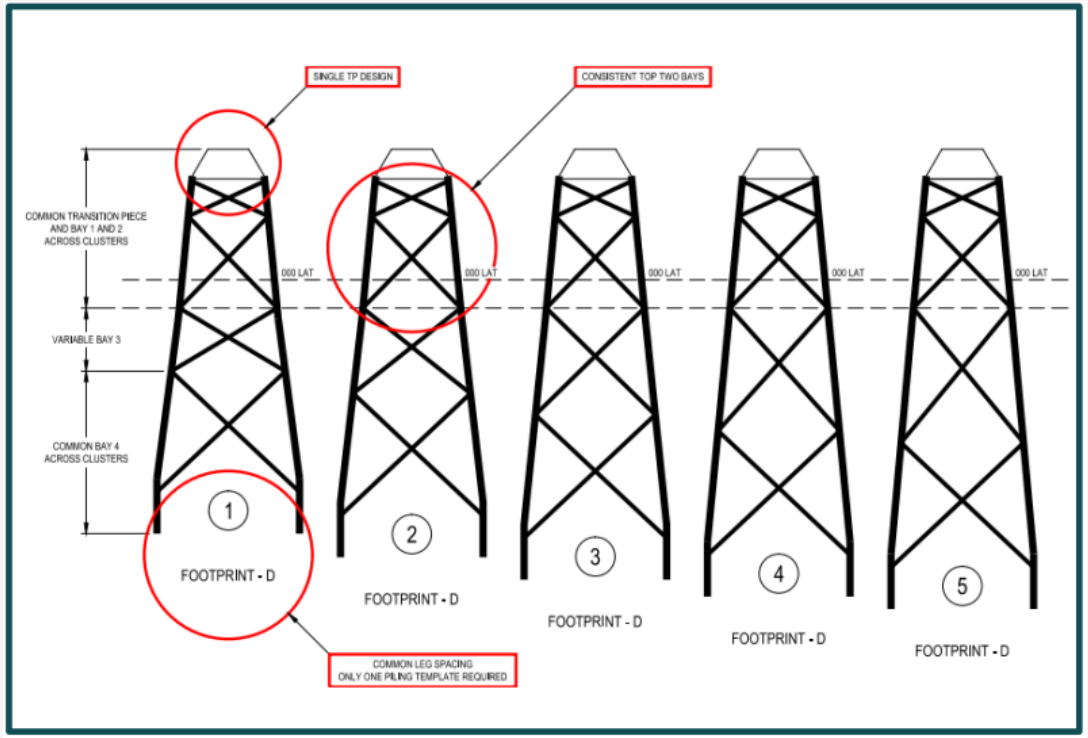
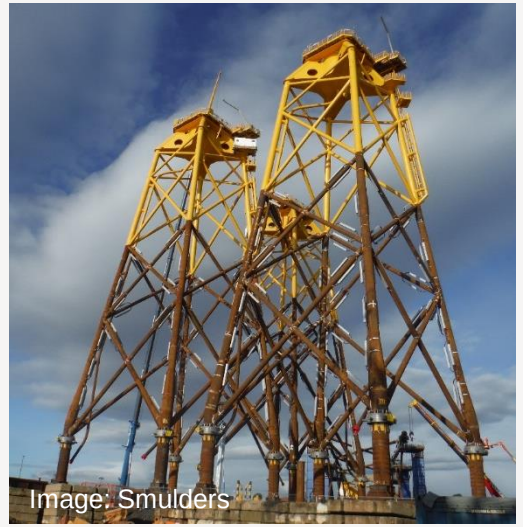
Design for Serial Fabrication

Common TP & Upper Jacket





Cluster Specific Lower Jacket

Installation

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Pile Installation risks

Boulders

Bedrock horizons

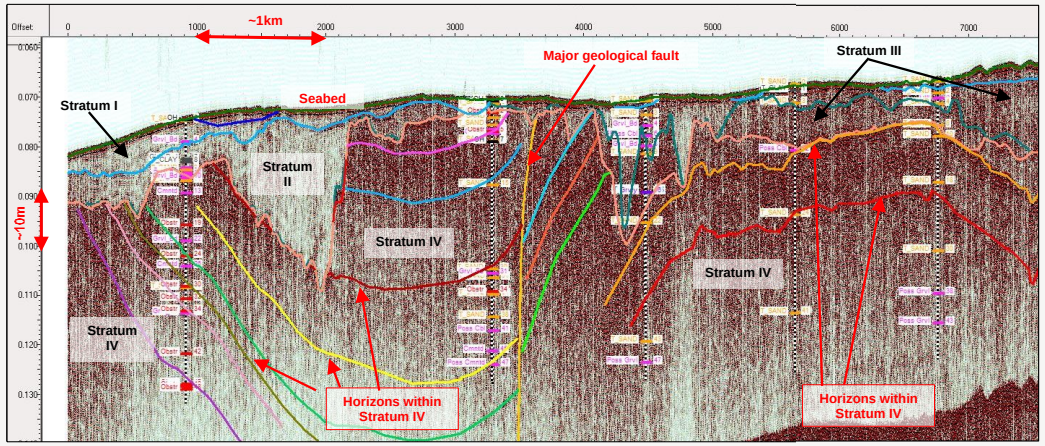
Strong and laterally traceable seismic reflectors

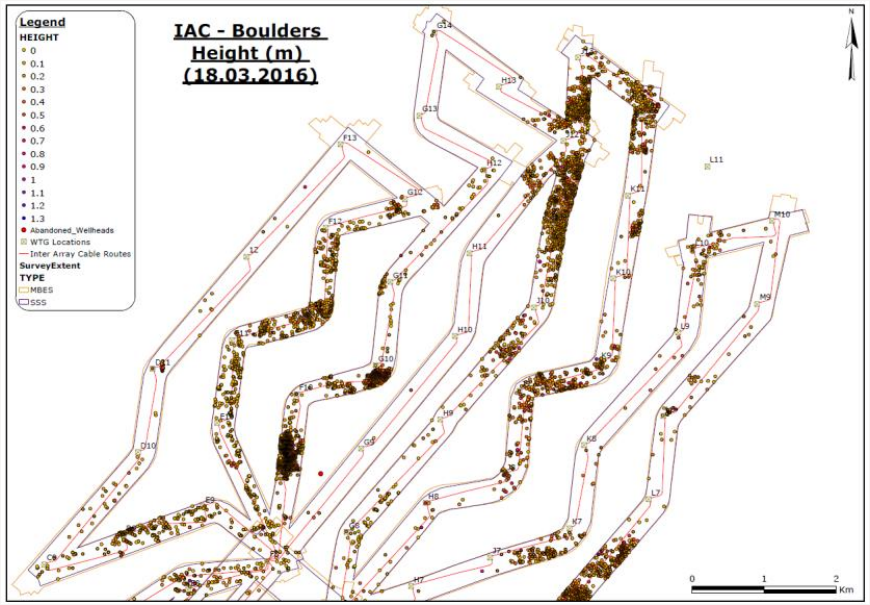
Identified in intact Lower Cretaceous

Variable in lateral extent

Some have corresponding evidence in the borehole data

Some relate to sandstone beds





Mitigation

Remediation = drive-drill-drive

Derive method to assess

Reduction of capacity from drilling

Shaft friction increase from ageing that can be relied upon

Capacity gain from concrete plug

Analyse impact of drilling at varying depths with and without concrete plug

Installation contractor has clear pre-defined scenarios to know instantly whether:

Pile must be abandoned,

Pile can be saved with a concrete plug

Pile does not require a concrete plug

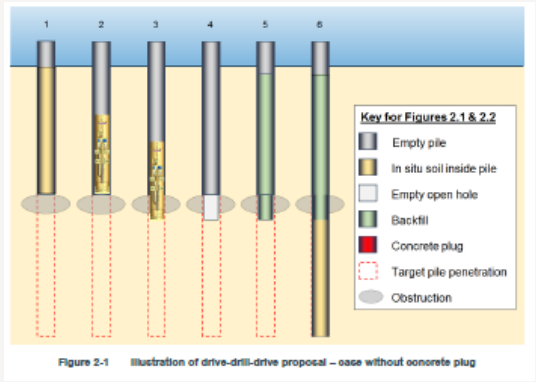


Figure 2-1 Illustration of drive-drill-drive proposal – case without concrete plug

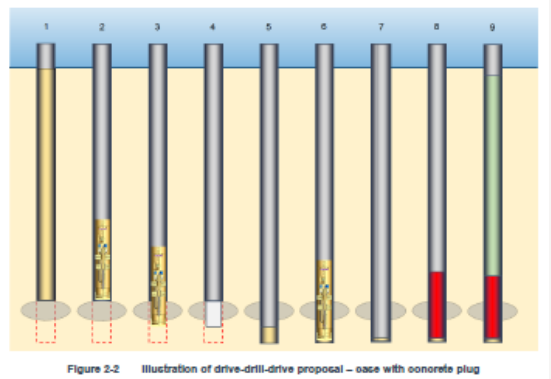
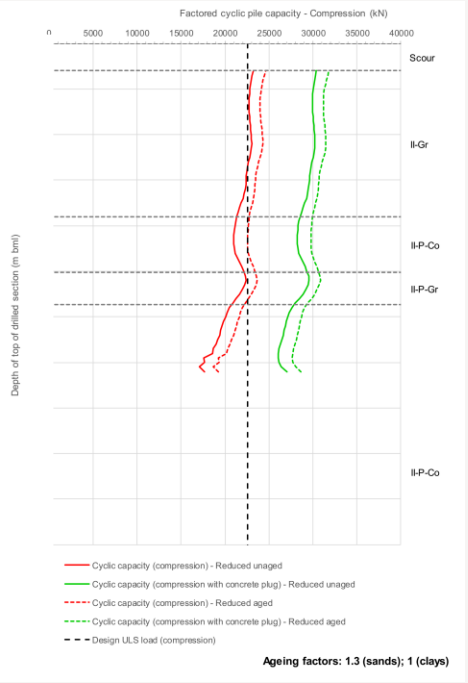


Figure 2-2 Illustration of drive-drill-drive proposal – case with concrete plug



Design Penetration	Pile Tip Penetration at Start of Drill-out					
	Single Drill-out FEASIBLE		Concrete Plug Required		Single Drill-out NOT FEASIBLE	
	from (m)	to (m)	from (m)	to (m)	from (m)	to (m)
40.0	0.0	40.0	20.0	40.0		
48.0	0.0	48.0	44.0	48.0		
44.9	0.0	39.5	38.0	39.5	39.5	41.5
	41.5	44.9	41.5	44.9		
39.7	0.0	35.5	22.0	27.0	35.5	37.5
			32.5	35.5		
	37.5	39.7	37.5	39.7		
43.8	0.0	43.8	40.0	43.8		
31.2	0.0	31.2	28.5	31.2		
28.5 [a]					0.0	28.5
37.6	0.0	37.6	28.0	37.6		
37.1	0.0	37.1	33.0	37.1		
43.0	0.0	43.0	16.0	43.0		
41.4 [a]					0.0	41.4
36.2	0.0	32.0			32.0	34.5
	34.5	36.2	34.5	36.2		
40.3	0.0	35.5			35.5	38.0
	38.0	40.3	38.0	40.3		
42.4	0.0	42.4	39.0	42.4		

Jacket Installation

- Transportation fatigue
- Upending vs vertical towing
- Installation vessel limits
- Early age cycling
- Safe access
  - Walk to work systems
  - Evacuation procedures

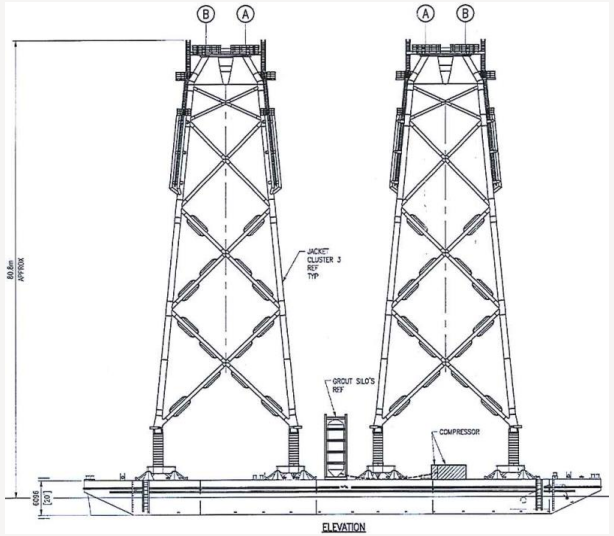


Image: SHL


Image: Ian Greenwood

Conclusions

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Conclusions

- Multi-disciplinary approach required to manage **risk** and optimise **standardisation**
- Good design should consider:
  - *Variable site conditions*
  - *Fabrication approach*
  - *Installation approach*
  - *Project programme*
  - *Through life user safety*
- Innovation, collaboration and adaptability are key to future success of industry.

Successes to date

- Design AFC and certification to programme
- Pile installation completed December 2017
- Jacket installation completed July 2018
- First power generation July 2018
- Fully operational in 2019

Image: BOWL

Thank you