Round 3 Firth of Forth Development Zone

Pile Driving Analysis – Additional Assessment including Drive-Drill-Drive Mode

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SUMMARY

Seagreen have commissioned Cathie Associates to produce a pile driving assessment for the Marr Bank 1 and 2 provinces of the Phase 1 of Round 3 Firth of Forth Offshore Wind Development. The purpose of this assessment is to provide supporting information for the environmental impact assessment, including impact energies, blow counts and the likely pile driving equipment required.

1 INTRODUCTION

Cathie Associates have been commissioned by Seagreen to undertake a preliminary pile driving assessment for the Marr Bank 1 and Marr Bank 2 provinces of the Phase 1 Firth of Forth Offshore Wind Development. This assessment has been undertaken to provide noise data for input into the Environmental Impact Assessment (EIA).

A preliminary pile driving assessment for all areas of Phase 1 was produced and reported as a technical memo in September 2011, reference C162T24-01 [1]. This initial technical memo provided preliminary pile driving data for the entire Phase 1, based on the derivation of four ground models.

This additional technical memo reports the results of the assessment of pile driving completed for the provinces of Marr Bank 1 and 2 only. The locations of these provinces are shown in drawing reference C162R16-D01-01, Appendix A.

2 SCOPE OF WORKS

This assessment comprises the following work items:

1. Production of geotechnical profiles by:
   - The review of existing ground investigation reports and GIS database.
   - The use of two representative depth to bedrock geological scenarios:
     - Mean Case Bedrock (MCB) 12m below seabed.
     - Deep Case Bedrock (DCB) 20m below seabed.
   - The selection of geotechnical parameters (Upper Bound (UB) and Best Estimate (BE)) values for each geological scenario.
2. Use the pile design methodology recommended by DNV[3] as implemented in the specialist software package ‘OPILE’ to determine the pile lengths required to support 6MW turbine loads for each scenario. 2m and 3m pile diameters and the following pile construction cases are to be considered:
   - Driving - Pile driving from seabed to target depth.
   - Drive Drill Drive - Pile driving from seabed to top of Triassic Group, drilling of rock socket and then driving to target depth through the rock socket.
3. Determine the preliminary Soil Resistance to Driving profiles (SRD) for each geotechnical profile and pile diameter (16 SRD’s in total).
4. Conduct an assessment of pile driving using the specialist software package ‘GRLWeap’ and the derived SRD profiles.
5. Derive the following for each scenario, construction case, and pile diameter required:
   - Recommended hammer size.
   - Blow count per change in efficiency.
   - Installation time.

Work items 2 through 5 were also run considering 7MW turbine loads for the DCB UB scenarios for both pile construction cases.

3 DESIGN LOADS

The adopted design loads have been extracted from the Foundation Concept Engineering Study Report No: A4MRSEAG-Z-ENG945-SRP-084, supplied by Seagreen [2].

Design Case 11 was selected, as it models a typical 7MW turbine, with a jacket foundation in 50 m water depth. This is considered to be a conservative representation of the possible range of installation conditions potentially implemented on the Phase 1 area. Those loads were then reduced by 12% in order to obtain an estimate of the loadings corresponding to a 6MW turbine as instructed by Seagreen. The loads adopted for a 6MW turbine are as follows:

- Maximum ULS Pile Compression Load 34, 070 kN
- Maximum ULS Pile Tension Load 25,970 kN

For a 7MW turbine the following loads were adopted:

- Maximum ULS Pile Compression Load 38,710 kN
- Maximum ULS Pile Tension Load 29,510 kN

These loads are understood to have been factored in accordance with DNV J101[3].

4 GEOLOGY OF MARR BANK ONE & MARR BANK TWO PROVINCES

The location and extent of Marr Bank 1 & 2 Provinces within Phase 1 of the Firth of Forth Offshore development is shown in drawing 162R16-D01-01, Appendix A. These provinces were defined by a maximum depth to rock head of 20m and the absence of Wee Bankie and Aberdeen Ground Formations.

4.1 Geological Units

The different geological units present in this site have been defined on the basis of a desk study and an intrusive ground investigation. The relevant information extracted for this assessment is summarised below.

4.1.1 Desk study and geophysical Survey

The initial desk study [4] indicated the geology of the entire Phase 1 area to comprise Holocene and Pleistocene deposits underlain by Triassic bedrock. The geophysical survey confirmed the presence of these formations and provided more detail regarding their extent and distribution.

The Holocene deposits encountered in the Marr Bank 1 and 2 provinces of Phase 1 comprise two formations: Undifferentiated Holocene sediments and Forth Formation. These formations are generally similar in composition predominantly comprising sand with occasional pockets of gravel. These two formations have been considered as Undifferentiated Holocene for the purposes of this assessment.

Marr Bank Formation is the only Pleistocene Formation present in Marr Bank 1 and 2 provinces. It is generally described as sand with abundant lithic gravel and pebbles. The lateral transition between Marr Bank formation (glacio-marine sediments) and Wee Bankie formation (glacial till) is situated to the west of Marr Bank provinces 1 & 2, and runs in a general north south orientation through the Phase 1 area. This transition is shown in drawing 162R16-D01-01.

The Triassic Group comprises sandstones, siltstones, mudstones and marls with thin sporadic bands of gypsum.

4.1.2 *Findings of the Geotechnical Survey*

The Phase 1 Geological Report is being prepared and has not as yet been issued. However the available borehole logs, CPT test data and laboratory testing completed to date has enabled a preliminary geological and geotechnical characterisation of the different formations for the purpose of this assessment. The formations encountered across the Marr Bank 1 & 2 Provinces can be typically described as follows:

- Undifferentiated Holocene. Loose to dense yellow and greyish brown silty fine to coarse SAND with shells, with occasional subordinate soft to stiff slightly silty clays.
- Marr Bank. Very dense dark grey silty fine SAND with sporadic pockets of clay, organic material and occasional silt layers.
- Undifferentiated Triassic. Extremely to moderately weak reddish brown laminated highly weathered SILTSTONE. Subordinate layers and units of very weak reddish brown fine grained SANDSTONE.

4.2 Geological Scenarios

The scenarios were developed following a review of the available geophysical data and the preliminary borehole logs and CPT data provided by the geotechnical survey. This assessment has been completed on the basis of two representative ground profiles or 'scenarios', defined as follows:

- Mean Case Bedrock (MCB). Models the mean depth to rock head, calculated across both; Marr Bank 1 and Marr Bank 2 provinces. This case is considered to represent the most likely pile lengths required.
- Deep Case Bedrock (DCB). Models the maximum depth to rock head for Marr Bank 1 and Marr Bank 2 provinces, defined in previous studies as 20m below seabed. This case is likely to require longer piles.

The scenarios represent the range of ground conditions present within Marr Bank 1 & 2. The formation thicknesses were derived from the available GIS data and are summarised in Table 1.

Table 1 – Geological Scenarios

Geological Unit	Formation levels (m below mud line)	
	Deep Case Bedrock	Mean Case Bedrock
Unit 1 Undifferentiated Holocene	0 – 5.6	0-5.6
Unit 2a Wee Bankie	Not present	Not present
Unit 2b Marr Bank	5.6- 20	5.6-12.2
Unit 3 Aberdeen Ground	Not present	Not present
Unit 4 Undifferentiated Triassic	20+	12.2+

5 GEOTECHNICAL PARAMETERS

Geotechnical parameters are required to determine the requisite pile lengths and for the derivation of soil resistance to driving (SRD) profiles. The derivation of geotechnical parameter values was made from available borehole descriptions, in-situ test data, laboratory test results and engineering judgement.

The Marr Bank Formation soils are typically cohesionless, however a significant cohesive silt portion has been observed locally. It was not deemed representative to model this detail at this level of assessment. Therefore, the Marr Bank has been considered only as a cohesionless unit.

The Triassic Group is generally described as extremely to moderately weak mudstone and siltstone, with the exception of the northeast of the site where it was described as sandstone. The mudstone and siltstone has potential for remoulding during driving, therefore in the absence of advanced testing this formation was modelled as a very hard cohesive material.

Pile capacity and driving resistance were calculated using the same relative values, i.e. both UB or both BE. The combination of parameters used for the geotechnical profiles are detailed in Tables 2 and 3.

Table 2 – Mean Case Bedrock Geotechnical Parameters

Unit (Major Fraction)	Unit Top Depth (mbsb)	Unit Bottom Depth (mbsb)	Thickness (m)	Effective (buoyant) Unit Weight (kN/m³)	Plasticity		Upper Bound Undrained Shear Strength (kPa)		Axial Resistance Parameters			
					Liquid Limit (%)	Plastic Limit (%)	Top of Unit (kPa)	Bottom of Unit (kPa)	Max Skin Friction (kPa)	Max End Bearing (kPa)	Friction Angle (degrees)	Bearing Capacity Factor
Mean Case Bedrock- Best Estimate Parameters												
Undifferentiated Holocene (SAND)	0	5.6	5.6	11	-	-	-	-	96	9600	30	40
Marr Bank (SAND)	5.6	12.2	6.6	9	-	-	-	-	96	9600	30	40
Undifferentiated Triassic (Modelled as CLAY)	12.2	>50m	>50m	12	38	21	1000	1200	-	-	-	-
Mean Case Bedrock - Upper Bound Parameters												
Undifferentiated Holocene (SAND)	0	5.6	5.6	11	-	-	-	-	96	9600	30	40
Marr Bank (SAND)	5.6	12.2	6.6	10	-	-	-	-	115	12000	35	50
Undifferentiated Triassic (Modelled as CLAY)	12.2	>50m	>50m	13.5	38	21	1000	1500	-	-	-	-

Table 3 – Deep Case Bedrock Geotechnical Parameters

Unit (Major Fraction)	Unit Top Depth (mbsb)	Unit Bottom Depth (mbsb)	Thickness (m)	Effective (buoyant) Unit Weight (kN/m³)	Plasticity		Upper Bound Undrained Shear Strength (kPa)		Axial Resistance Parameters			
					Liquid Limit (%)	Plastic Limit (%)	Top of Unit (kPa)	Bottom of Unit (kPa)	Max Skin Friction (kPa)	Max End Bearing (kPa)	Friction Angle (degrees)	Bearing Capacity Factor
Deep Case Bedrock- Best Estimate Parameters												
Undifferentiated Holocene (SAND)	0	5.6	5.6	11	-	-	-	-	96	9600	30	40
Marr Bank (SAND)	5.6	20	6.6	9	-	-	-	-	96	9600	30	40
Undifferentiated Triassic (Modelled as CLAY)	20	>50m	>50m	12	38	21	1000	1200	-	-	-	-
Deep Case Bedrock - Upper Bound Parameters												
Undifferentiated Holocene (SAND)	0	5.6	5.6	11	-	-	-	-	96	9600	30	40
Marr Bank (SAND)	5.6	20	6.6	10	-	-	-	-	115	12000	35	50
Undifferentiated Triassic (Modelled as CLAY)	20	>50m	>50m	13.5	38	21	1000	1500	-	-	-	-

6 PILE DESIGN

6.1 Methodology

The preliminary pile design followed the methodologies recommended by the standard DNV J101 [3] and was implemented with the Cathie Associates' commercial software package OPile [5]. Relevant details of this methodology are presented in the following sections.

6.1.1 Evaluation of Static Skin Friction & End Bearing Capacity

The ultimate bearing capacity of a single pile, Q_d, is determined from the following equation[3].

$$Q_d = Q_f + Q_p = \Sigma f A_s + q A_a$$

Where:

Q_f = skin friction, kN,

Q_p = total end bearing, kN,

f = unit skin friction capacity, kPa,

A_s = external pile shaft area, m²,

q = unit end bearing capacity, kPa,

A_a = base area of pile, m².

The base area is only taken into account if the pile is calculated as being plugged during installation and at the final target penetration. In the unplugged condition, the internal skin friction is taken into account to quantify the total shaft resistance.

6.1.2 Cohesive Soils

The (static) unit shaft friction in clay, f, is calculated by the following empirical equation for total stress methods [3]:

$$f = \alpha S_u$$

Where:

S_u is the undrained shear strength and a is the adhesion factor calculated by:

$\alpha = 0.5 (S_u/p')^{-0.5}$ for $(S_u/p') \leq 1.0$

$\alpha = 0.5 (S_u/p')^{-0.25}$ for $(S_u/p') > 1.0$

Where:

p' is the effective overburden pressure, in kPa, at the depth being considered.

For piles end bearing in cohesive soils, the unit end bearing, *q*, in kPa is computed from:

$$q = 9S_u$$

6.1.3 Cohesionless Soils

For pipe piles in cohesionless soils, the shaft friction, *f*, in kPa, is calculated as follows:

$$f = k\, p_o \tan \delta$$

Where:

K = coefficient of lateral earth pressure at rest, taken as 0.8 for tension and compression,

p_o = effective overburden pressure, kPa, at the depth being considered,

δ = friction angle between the soil and the pile wall.

For piles end bearing in cohesionless soil, the unit end bearing, q may be computed from the following:

$$q = p_0 N_q$$

Where:

N_q is a dimensionless bearing capacity factor.

Limiting values of skin friction and end bearing were applied in cohesionless soil as per DNV J101 recommendations.

A factor of safety of 1.25 on the characteristic soil resistances calculated was applied to derive the allowable soil resistance used to determine the final pile length.

Two construction methods were considered:

- Piles driven to depth. The smallest of the plugged and unplugged capacity calculations was selected as design resistance value.
- Piles driven to bedrock, drilled to final depth and driven through the rock socket. In this case the internal skin friction was reduced and the end bearing was calculated considering the annulus of the pile only.

6.2 Pile Sizing

Seagreen's conceptual design engineering was based on the following pile sizes:

- 2m diameter, 60mm wall thickness
- 3m diameter, 60mm wall thickness

The required pile lengths and diameters for the scenarios considered are summarised below and example calculations are contained in Appendix B.

Table 4 –Pile Lengths Adopted for Driving Assessment

Scenario (Geotechnical parameters)	**2m Diameter Pile Length (m)**	**3m Diameter Pile Length (m)**
Pile Drive Mode		
MCB BE 6MW	27	22
MCB UB 6MW	25	21
DCB BE 6MW	32	27
DCB UB 6MW	30	26
DCB UB 7MW	32	27
Drive-Drill-Drive Mode		
MCB BE 6MW	29	24
MCB UB 6MW	27	22
DCB BE 6MW	35	29
DCB UB 6MW	32	27
DCB UB 7MW	34	29

The 2m diameter piles require a greater length to support the loads applied. The pile lengths calculated for the drive-drill-drive mode are slightly longer as would be expected from the minimal internal skin friction and end bearing area limited to the pile annulus.

7 PILE DRIVING ASSESSMENT

A pile driving assessment was undertaken with the wave equation analysis method on the basis of estimated soil resistance to driving profiles (SRD) for each scenario, set of geotechnical properties, loadings and pile size. The wave equation method models the impact energy and blow counts required to drive the piles to the required depths. This model was completed using the software program GRLWEAP [6].

7.1 Soil Resistance to Driving

The soil resistance to driving (SRD) profiles are estimated from empirical relationships with static resistance as explained in the following sections.

7.1.1 Sand (Undifferentiated Holocene and Marr Bank Formation)

The static shaft friction and end bearing capacities are calculated following the DNV method [3]. The limiting skin frictions and end bearing values specified in DNV J101 for granular materials were also adopted. However, for sand, the dynamic resistance factor on static shaft friction is taken as 0.7 in accordance to the Stevens Method [7].

Dynamic Shaft Capacity, SRD = 0.7 x Static Capacity

Dynamic End bearing Capacity, SRD = End Bearing Capacity

7.1.2 Clay (Triassic Group)

The empirical method proposed by Stevens [7] was adopted to estimate the shaft resistance of this Group during driving. The static shaft resistance was estimated from DNV J101 [3] and then reduced by applying a Dynamic Resistance Factor (F_p) to calculate the dynamic shaft resistance.

$F_p = 0.5(OCR)^{0.3}$

Where,

OCR = Over-consolidation ratio $[S_{u\ (oc)} / S_{u\ (nc)}]^{1/0.85}$

$S_{u\ (oc)}$ = Undrained shear strength of over-consolidated clay,

$S_{u\ (nc)}$ = Undrained shear strength of normally-consolidated clay, where:

In calculating OCR, the value of $S_{u(nc)}$ is calculated using the effective overburden stress, p'_0, from the following equation:

$S_{u\ (nc)} = \sigma_v\,(0.11 + 0.0037PI)$, and

PI = Plasticity Index

Mercia Mudstone behaves as a ‘lightly’ to ‘moderately’ over consolidated clay[8] . An OCR of 1 has been adopted for this formation in the absence of detailed geotechnical testing.

In summary the following Dynamic Resistance Factors were applied for the Triassic Group:

Shaft capacity, SRD = F_p x Static Capacity

End bearing Capacity, SRD = 1.0 x End Bearing Capacity

7.1.3 Influence of construction methods

Driven piles

The pile driving mode is typically unplugged (coring) when piles are initially driven. On further penetration, the pile driving mode may become 'plugged' when the internal shaft resistance (inside the pile) exceeds the end bearing resistance acting on the area of soil within the pile annulus. It should be noted that plugged piles may subsequently unplug with further driving. This typically occurs when significant increases in end bearing resistance are encountered. The depth of plugging cannot be predicted accurately and depends on local soil conditions, driving energy and pile diameter.

The final SRD profile was based on the smaller soil capacity obtained when comparing the plugged and unplugged modes in their static condition.

Drive-drill-drive

As detailed in Section 2, the pile shall be driven through Holocene and Pleistocene sediment to bedrock, a rock socket will then be drilled and the pile driven to target depth through the rock socket. Therefore, the internal shaft resistance to driving was ignored when deriving the SRD for piles drilled through the Triassic Group. Drilled Sockets of 1m and 1.25m diameter were considered for 2m diameter and 3m diameter piles respectively in order to quantify the volume of debris accumulated inside the hollowed pile when driving through a drilled socket. It was assumed that the debris would generate a magnitude of internal skin friction proportional to its own volume.

7.1.4 Influence of soil set up

The effects of increasing axial pile capacity with time and enhanced resistance to driving are documented in numerous papers [9 & 10]. The construction of drilled sockets in the Triassic Group would require the use of drilling techniques. The change of construction techniques from driving to drilling and finally driving through the rock socket may take several hours or, in case of unfavourable weather conditions, several days.

A set up factor of 2 was applied to the total external skin friction and end bearing values in the first 2m of the Triassic Group to calculate the SRD in the case of drive-drill-drive mode. This assumption is based on the data presented by Jardine et all (2005), 'ICP methods for driven piles in sands and clays' [9] and the approach discussed in Skov R and Denver H (1988), 'Time-dependence of bearing capacity of piles Proc. 3rd Int. Conf. on Application of Stress-wave Theory to Piles (Ottawa, Canada, 25-27 May 1988)' [10] and is considered adequate for delays up to 20 days between drilling and driving.

7.2 Pile Driving Assessment

The SRD profiles, pile sizes and target depths were modelled in GRLWEAP for a range of hammer sizes.

A maximum hammer operating efficiency of 95% was used to define the likely hammer size required to drive the piles. A hammer efficiency of 95% corresponds to global efficiencies of approximately 90%. The global efficiency is defined as the ratio between the ENTHRU energy (energy transmitted to the pile) and the maximum rated energy of the hammer.

The wave equation analysis shall use the following input parameters, adopted from the preliminary pile driving assessment for all areas of Phase 1, reference C162T24-01 [1]:

Table 5 – Wave Equation Parameters

Parameter	Cohesive	Cohesionless
Quake – shaft	2.5mm	2.5mm
Quake – toe	2.5mm	2.5mm
Damping – shaft	0.2	0.2
Damping – toe	0.5	0.5

A preliminary pile driving assessment was completed by assuming a rate of 400 blows per metre as the refusal criteria for each scenario to determine the hammer size. This preliminary assessment of hammer size assumed the piling hammer to be operating at 95% efficiency for the entire duration of the installation operations.

A more detailed driving assessment was then completed for each scenario and pile size as follows:

- An initial hammer efficiency of 15% is applied from mud line level until a limit of 100 blows per meter is achieved.
- Once the limit is achieved, the hammer efficiency is increased in 20% intervals to final penetration.

The results of the pile drivability assessment were exported to a table, which is presented in Appendix C. A summary of the results is presented in tables 6 & 7 below.

Table 6 – Pile driving to full depth.

Scenario	Pile diameter (m)	Piling Summary						
		Penetration Depth (m)	Max SRD (MN)	Hammer	Hammer efficiency	Max Impact Energy (kJ)	Total No. of blows	Duration (hours)
MCB BE 6MW	2	27	78.5*	IHC-S1800	15-95%	1420	2316	0.9
	3	22	61	IHC-S1800	15-95%	1436	1329	0.5
MCB UB 6MW	2	25	90.8**	IHC S2300	15-95%	2056	1553	0.6
	3	21	67.6	IHC-S2300	15-95%	2081	893	0.3
DCB BE 6MW	2	32	78.1***	IHC-S1800	15-95%	1432	2381	0.9
	3	27	56.6	IHC-S1800	15-95%	1449	1406	0.5
DCB UB 6MW	2	30	58.3	IHC-S1800	15-95%	1445	1597	0.6
	3	26	63.2	IHC-S1800	15-95%	1446	1393	0.5
DCB UB 7MW	2	<32	Refusal with maximum hammer size of IHC S2300****					
	3	27	69	IHC 1800	15-95%	1449	1449	0.5
Range	2-3	21-32	56.6-91	IHC 1800	15-95%	1420-2081	893-2381	0.5-0.9

*Plugged at 24m, **Plugged at 25m, ***Plugged at 30m, ****Maximum hammer considered, assumes plugging at depth.

Table 7 – Pile driving to bedrock and drilled socket in the Triassic Group

Scenario	Pile diameter (m)	Piling Summary						
		Penetration Depth (m)	Max SRD (MN)	Hammer	Hammer efficiency	Max Impact Energy (kJ)	Total No. of blows	Duration (hours)
MCB BE 6MW	2	29	40.8	IHC-S1200	15-75%	916	1445	0.5
	3	24	40.3	IHC-S1200	15-75%	920	1362	0.5
MCB UB 6MW	2	27	40.8	IHC-S1200	15-75%	915	1351	0.5
	3	22	49	IHC-S1200	15-75%	919	1081	0.4
DCB BE 6MW	2	35	39.4	IHC-S1200	15-75%	870	2061	0.8
	3	29	46.3	IHC-S1200	15-75%	870	1746	0.6
DCB UB 6MW	2	32	40.3	IHC-S1200	15-75%	869	1802	0.7
	3	27	47.7	IHC-S1200	15-75%	869	1662	0.6
DCB UB 7MW	2	34	45.6	IHC-S1200	15-95%	1100	2062	0.8
	3	29	55.6	IHC-S1200	15-95%	1099	2199	0.8
Range	2-3	22-34	39.4-55.6	IHC-S1200	15-95%	870-1100	1081-2199	0.5-0.9

The piling durations have been preliminarily assessed by assuming a hammer frequency of 45 blows/meter and uninterrupted driving operations. The total durations anticipated (assuming continuous driving) are presented in Appendix C. A summary of the results is presented in Table 7.

The Triassic Group shows significantly higher resistance to driving than the overlying Marr Bank Formation and Undifferentiated Holocene Formation.

8 INDICATIVE PILING DURATIONS

Indicative piling operation timings for drive-drill-drive and driven piling are provided in Table 8. These timings have been derived from records from recent piling operations in similar ground conditions (source confidential); however piling operations vary significantly depending upon the contractor, installation vessel, weather and plant. The following assumptions have been made in the derivation of these timings:

- The installation vessel is a self-propelled jack-up.
- A single four pile jacket structure is the sub-structure
- The drilling operation is top driven.
- The drill bit diameter is 1.7m.
- The drilling operation is a single run.
- No significant problems and optimum weather conditions.
- Deep bedrock case, 2m diameter pile, with a toe depth of 27m BSBL.

Table 8 – Indicative Pile Timings

Operation	Driven Piling Operations				Drive Drill Drive Piling Operations			
	Pile 1	Pile 2	Pile 3	Pile 4	Pile 1	Pile 2	Pile 3	Pile 4
On-site and Jack-up	2hrs	2hrs	2hrs	2hrs	2hrs	2hrs	2hrs	2hrs
Deployment and set-up of piling template	4hrs	NA	NA	NA	4hrs	NA	NA	NA
Pile placement and self-weight settle	2hrs	2hrs	2hrs	2hrs	2hr	2hrs	2hrs	2hrs
Piling set-up and setting blows	2hrs	2hrs	2hrs	2hrs	1.5hrs	1.5hrs	1.5hrs	1.5hrs
Pile Driving	1hr	1hr	1hr	1hr	0.5hrs	0.5hrs	0.5hrs	0.5hrs
Remove Hammer and Install Drill Rig	NA	NA	NA	NA	6hrs	6hrs	6hrs	6hrs
Top Drill and Reaming	NA	NA	NA	NA	15hrs	15hrs	15hrs	15hrs
Remove drill rig and reinstall Hammer	NA	NA	NA	NA	4hrs	4hrs	4hrs	4hrs
Piling (re) set-up	NA	NA	NA	NA	1hr	1hr	1hr	1hr
Pile Driving (Restart)	NA	NA	NA	NA	1hr	1hr	1hr	1hr
Post Piling ops	1hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr
Recovery of piling template	NA	NA	NA	3hrs	NA	NA	NA	3hr
Jack down	2hrs	2hrs	2hrs	2hrs	2hrs	2hrs	2hrs	2hrs
Transiting to next location and positioning	1hr	1hr	1hr	NA/Unknown	1hr	1hr	1hr	NA/Unknown
Per pile Total	**15hrs**	**11hrs**	**11hrs**	**13hrs**	**41hrs**	**37hrs**	**37hrs**	**39hrs**
JACKET TOTAL	**50hrs**				**154hrs**			

9 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this assessment:

- A significant range of driving energies, blow counts and durations can be expected during the piling work operations.
- The range of impact energies associated with drive-drill-drive mode is significantly lower than on driven mode only.
- The MCB UB 6MW scenario for full depth pile driving requires very high impact energies to achieve target penetration. Due to a number of issues, including the noise generated and its potential effect on marine mammals, this installation scenario is not considered to be a feasible method of installing piles in these circumstances. Therefore, for this scenario drive-drill-drive installation should be considered.
- The delays associated with changes between driving and drilling techniques cannot be predicted accurately and will depend on the contractors' method of work, however significant 'pile set-up' is expected.
- The possibility of plugging, particularly on the 2m diameter piles when driven though the Triassic Group cannot be accurately predicted.
- The use of 2m diameter piles will result in a risk of refusal before target depth and adequate pile capacity is achieved.

This is a preliminary assessment based upon preliminary ground investigation information. We recommend that this assessment is re-visited on receipt of more detailed geological and/or geotechnical data.

10 REFERENCES

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9. Jardine et all (2005), ICP methods for driven piles in sands and clays'. Thomas Telford.
10. 'Skov R and Denver H (1988) Time-dependence of bearing capacity of piles Proc. 3rd Int. Conf. on Application of Stress-wave Theory to Piles (Ottawa, Canada, 25-27 May 1988)'

Appendix A

Location of Marr Bank 1 & Marr Bank 2 Provinces.

Drawing 162R16-001-01

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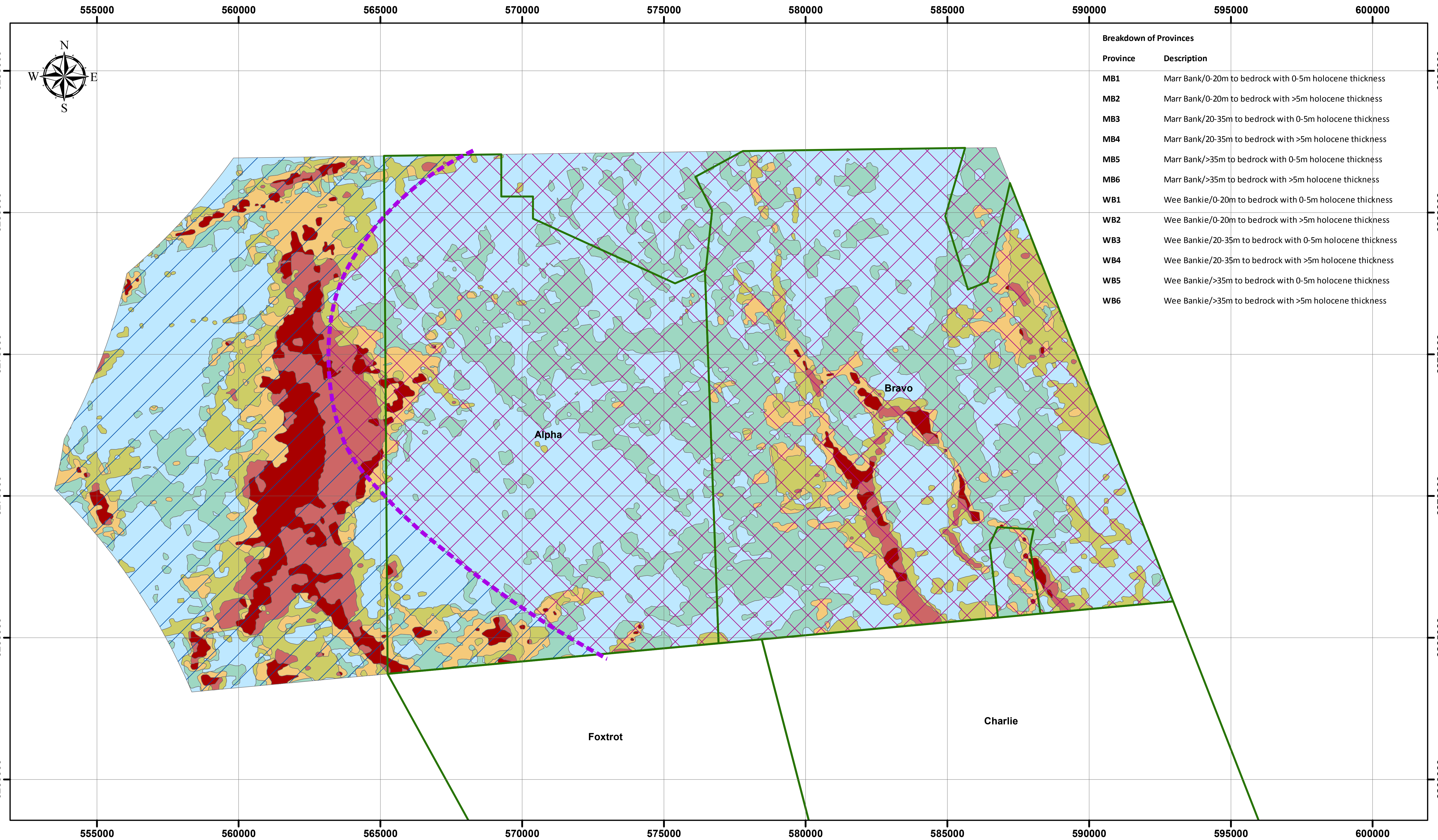
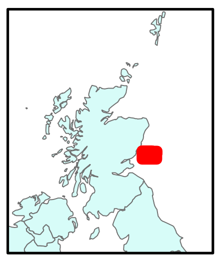


Breakdown of Provinces

Province	Description
MB1	Marr Bank/0-20m to bedrock with 0-5m holocene thickness
MB2	Marr Bank/0-20m to bedrock with >5m holocene thickness
MB3	Marr Bank/20-35m to bedrock with 0-5m holocene thickness
MB4	Marr Bank/20-35m to bedrock with >5m holocene thickness
MB5	Marr Bank/>35m to bedrock with 0-5m holocene thickness
MB6	Marr Bank/>35m to bedrock with >5m holocene thickness
WB1	Wee Bankie/0-20m to bedrock with 0-5m holocene thickness
WB2	Wee Bankie/0-20m to bedrock with >5m holocene thickness
WB3	Wee Bankie/20-35m to bedrock with 0-5m holocene thickness
WB4	Wee Bankie/20-35m to bedrock with >5m holocene thickness
WB5	Wee Bankie/>35m to bedrock with 0-5m holocene thickness
WB6	Wee Bankie/>35m to bedrock with >5m holocene thickness

Location Map



Legend

Split Between Marr Bank and Wee Bankie

Province

MB1 MB2 MB3 MB4 MB5 MB6 WB1 WB2 WB3 WB4 WB5 WB6

Projection/Scale

WGS_1984_UTM_Zone_30N
Projection: Transverse_Mercator
False_Easting: 500000.000000
False_Northing: 0.000000
Central_Meridian: -3.000000
Scale_Factor: 0.999600
Latitude_Of_Origin: 0.000000
Linear Unit: Meter

GCS_WGS_1984
Datum: D_WGS_1984

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CATHIE ASSOCIATES

Seagreen WIND ENERGY

Revision Status

Rev	Date	Details of Changes	Dr'n	Ch'k
1	15/02/12	First Issue	PSL	MRO

Firth of Forth Offshore Wind Farm

R16 - Phase 1 Development Zone Interpretive Report

Province Map

C162R16-D01-01	PSL	Rev 1

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Appendix B

Example of Pile Sizing Calculations

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PILE DRIVING ASSESSMENT
Pile Sizing Calculations

MCB_BE 6MW

CATHIE ASSOCIATES

Requirement

Pile Diameter	Jacket Compress (MN)	Jacket Tension (MN)
2m	34.07	25.97
3m	34.07	25.97

1.25 resistance factor applied to soil resistances (DNV-OS-J101)

Results

Pile Diameter	Required Pile Length	Capacity Compress	Capacity Tens	Utilisation Compress	Utilisation Tens	Hammer Type/Size
2m	27	51.80	27.50	0.66	0.94	**IHC-S1800**
3m	22	55.97	26.52	0.61	0.98	**IHC-S1800**

2m Pile Diameter

Final Pen (m)	End Capacity Plugged (kN)	End Capacity Unplug (kN)	Cum Friction Compres (kN)	Cum Friction Tension (kN)	Factored Tension (kN)	Total Capacity Plugged (kN)	Total Capacity Unplugged (kN)	Plugged/Unplu	Total Capacity (kN)	Factored Total Capacity (kN)
0	0	0	0	0	0	0	0	PLUGGED	0	0
3	0	0	0	0	0	0	0	PLUGGED	0	0
3	4147	516	36	36	28.6	4182.7	552	UNPLUGGED	552	442
4	5529	782	147	147	117.984	5676.7	930	UNPLUGGED	930	744
5	6912	1078	291	291	232.912	7202.6	1369	UNPLUGGED	1369	1095
6	7741	1270	393	393	314.12	8133.5	1663	UNPLUGGED	1663	1330
7	8872	1582	584	584	467.584	9456.3	2167	UNPLUGGED	2167	1733
7	9324	1714	669	669	534.816	9992.8	2382	UNPLUGGED	2382	1906
8	10455	2060	897	897	717.536	11352.1	2957	UNPLUGGED	2957	2366
9	11586	2431	1151	1151	921.12	12737.6	3582	UNPLUGGED	3582	2866
10	12717	2826	1432	1432	1145.68	14149.2	4259	UNPLUGGED	4259	3407
11	13848	3246	1739	1739	1391.04	15587	4985	UNPLUGGED	4985	3988
12	14979	3691	2072	2072	1657.36	17050.8	5763	UNPLUGGED	5763	4610
12	15205	3783	2141	2141	1713.12	17346.7	5924	UNPLUGGED	5924	4739
13	28424	7088	4021	4021	3216.4	32444.5	11108	UNPLUGGED	11108	8887
14	28544	8549	5560	5560	4448.24	34103.9	14110	UNPLUGGED	14110	11288
15	28693	10417	7529	7529	6022.88	36221.8	17945	UNPLUGGED	17945	14356
16	28843	12328	9543	9543	7634.72	38386.2	21872	UNPLUGGED	21872	17497
17	28992	14281	11603	11603	9282.24	40595.2	25884	UNPLUGGED	25884	20707
18	29142	16275	13705	13705	10964.16	42847.2	29980	UNPLUGGED	29980	23984
19	29292	18308	15849	15849	12679.36	45140.8	34157	UNPLUGGED	34157	27326
20	29441	20379	18034	18034	14426.8	47474.7	38412	UNPLUGGED	38412	30730
21	29591	22486	20257	20257	16205.68	49847.9	42743	UNPLUGGED	42743	34194
22	29740	24630	22519	22519	18015.12	52259.3	47148	UNPLUGGED	47148	37719
23	29890	26808	24818	24818	19854.32	54707.9	51626	UNPLUGGED	51626	41301
24	30040	29021	27153	27153	21722.72	57193	56174	UNPLUGGED	56174	44939
25	30189	31267	29525	29525	23619.68	59713.8	60792	PLUGGED	59714	47771
26	30339	33546	31931	31931	25544.56	62269.5	65477	PLUGGED	62270	49816
27	30488	35858	34371	34371	27496.96	64859.6	70229	PLUGGED	64860	51888
28	30638	38201	36845	36845	29476.32	67483.4	75046	PLUGGED	67483	53987
29	30788	40575	39353	39353	31482.24	70140.4	79928	PLUGGED	70140	56112
30	30937	42980	41893	41893	33514.32	72830.1	84873	PLUGGED	72830	58264
31	31087	45416	44465	44465	35572.08	75551.9	89881	PLUGGED	75552	60442
32	31236	47881	47069	47069	37655.28	78305.5	94950	PLUGGED	78306	62644
33	31386	50376	49705	49705	39763.6	81090.5	100080	PLUGGED	81091	64872
34	31536	52899	52371	52371	41896.56	83906.3	105270	PLUGGED	83906	67125
35	31685	55452	55068	55068	44054.08	86752.8	110519	PLUGGED	86753	69402
36	31835	58033	57795	57795	46235.68	89629.4	115827	PLUGGED	89629	71704
37	31984	60642	60552	60552	48441.28	92536	121193	PLUGGED	92536	74029
38	32134	63278	63338	63338	50670.48	95472.1	126616	PLUGGED	95472	76378
39	32284	65943	66154	66154	52923.12	98437.5	132097	PLUGGED	98438	78750
40	32433	68634	68999	68999	55199.04	101432	137633	PLUGGED	101432	81146
41	32583	71353	71872	71872	57497.92	104455.2	143225	PLUGGED	104455	83564
42	32732	74098	74775	74775	59819.68	107507	148873	PLUGGED	107507	86006
43	32882	76870	77705	77705	62164	110587	154575	PLUGGED	110587	88470
44	33032	79669	80663	80663	64530.72	113695	160332	PLUGGED	113695	90956
45	33181	82493	83650	83650	66919.76	116830.9	166143	PLUGGED	116831	93465
46	33331	85344	86664	86664	69330.96	119994.5	172007	PLUGGED	119995	95996
47	33480	88220	89705	89705	71764	123185.4	177925	PLUGGED	123185	98548
48	33630	91122	92774	92774	74218.96	126403.7	183896	PLUGGED	126404	101123
49	33780	94049	95869	95869	76695.52	129649	189919	PLUGGED	129649	103719
50	33929	97002	98992	98992	79193.6	132921.2	195994	PLUGGED	132921	106337

3m Pile Diameter

Final Pen (m)	End Capacity Plugged (kN)	End Capacity Unplug (kN)	Cum Friction Compres (kN)	Cum Friction Tension (kN)	Factored Tension (kN)	Total Capacity Plugged (kN)	Total Capacity Unplugged (kN)		Total Capacity (kN)	Factored Total Capacity
0.1	0	0	0	0	0	0	0	PLUGGED	0	(kN)
3.9	0	0	0	0	0	0	0	PLUGGED	0	0
4	12440.7	993.51	18.91	18.91	15.128	12459.6	1012.4	UNPLUGGED	1012.4	810
5	15550.9	1444.2	234.39	234.39	187.512	15785.3	1678.6	UNPLUGGED	1678.6	1343
5.6	17417	1736.7	386.67	386.67	309.336	17803.7	2123.4	UNPLUGGED	2123.4	1699
6.6	20527.2	2260.9	678.76	678.76	543.008	21205.9	2939.7	UNPLUGGED	2939.7	2352
7	21771.2	2483.5	809.01	809.01	647.208	22580.2	3292.5	UNPLUGGED	3292.5	2634
8	24881.4	3072.1	1168.1	1168.1	934.48	26049.6	4240.3	UNPLUGGED	4240.3	3392
9	27991.6	3706.7	1575.2	1575.2	1260.16	29566.7	5281.8	UNPLUGGED	5281.8	4225
10	31101.8	4387.2	2030.1	2030.1	1624.08	33131.8	6417.3	UNPLUGGED	6417.3	5134
11	34211.9	5113.7	2532.8	2532.8	2026.24	36744.8	7646.6	UNPLUGGED	7646.6	6117
12	37322.1	5886.2	3083.5	3083.5	2466.8	40405.6	8969.7	UNPLUGGED	8969.7	7176
12.2	37944.2	6046.2	3199.4	3199.4	2559.52	41143.5	9245.6	UNPLUGGED	9245.6	7396
13.2	63617.2	10819.8	6075.2	6075.2	4860.16	69692.5	16895	UNPLUGGED	16895	13516
14	63617.2	13060	8408.7	8408.7	6726.96	72026	21468.7	UNPLUGGED	21468.7	17175
15	63617.2	15898	11365.1	11365.1	9092.08	74982.3	27263.1	UNPLUGGED	27263.1	21810
16	63617.2	18776.5	14363.4	14363.4	11490.72	77980.7	33139.9	UNPLUGGED	33139.9	26512
17	63617.2	21693.7	17402.2	17402.2	13921.76	81019.4	39095.8	UNPLUGGED	39095.8	31277
18	63617.2	24648.1	20479.7	20479.7	16383.76	84096.9	45127.7	UNPLUGGED	45127.7	36102
19	63617.2	27638.4	23594.6	23594.6	18875.68	87211.8	51232.9	UNPLUGGED	51232.9	40986
20	63617.2	30663.3	26745.5	26745.5	21396.4	90362.8	57408.8	UNPLUGGED	57408.8	45927
21	63617.2	33721.7	29931.4	29931.4	23945.12	93548.6	63653.1	UNPLUGGED	63653.1	50922
22	63617.2	36812.6	33151	33151	26520.8	96768.2	69963.5	UNPLUGGED	69963.5	55971
23	63617.2	39934.8	36403.4	36403.4	29122.72	100020.6	76338.2	UNPLUGGED	76338.2	61071
24	63617.2	43087.6	39687.5	39687.5	31750	103304.8	82775.1	UNPLUGGED	82775.1	66220
25	63617.2	46270	43002.6	43002.6	34402.08	106619.8	89272.6	UNPLUGGED	89272.6	71418
26	63617.2	49481.3	46347.6	46347.6	37078.08	109964.9	95829	UNPLUGGED	95829	76663
27	63617.2	52720.7	49722	49722	39777.6	113339.2	102442.7	UNPLUGGED	102442.7	81954
28	63617.2	55987.4	53124.8	53124.8	42499.84	116742.1	109112.3	UNPLUGGED	109112.3	87290
29	63617.2	59280.9	56555.5	56555.5	45244.4	120172.8	115836.4	UNPLUGGED	115836.4	92669
30	63617.2	62600.4	60013.3	60013.3	48010.64	123630.6	122613.7	UNPLUGGED	122613.7	98091
31	63617.2	65945.4	63497.7	63497.7	50798.16	127114.9	129443.1	PLUGGED	127114.9	101692
32	63617.2	69315.3	67008	67008	53606.4	130625.2	136323.2	PLUGGED	130625.2	104500
33	63617.2	72709.5	70543.7	70543.7	56434.96	134160.9	143253.2	PLUGGED	134160.9	107329
34	63617.2	76127.6	74104.2	74104.2	59283.36	137721.4	150231.8	PLUGGED	137721.4	110177
35	63617.2	79569	77689	77689	62151.2	141306.2	157258	PLUGGED	141306.2	113045
36	63617.2	83033.4	81297.7	81297.7	65038.16	144914.9	164331.1	PLUGGED	144914.9	115932
37	63617.2	86520.2	84929.8	84929.8	67943.84	148547	171449.9	PLUGGED	148547	118838
38	63617.2	90029	88584.8	88584.8	70867.84	152202	178613.7	PLUGGED	152202	121762
39	63617.2	93559.4	92262.3	92262.3	73809.84	155879.5	185821.7	PLUGGED	155879.5	124704
40	63617.2	97111	95961.9	95961.9	76769.52	159579.2	193073	PLUGGED	159579.2	127663
41	63617.2	100683.5	99683.3	99683.3	79746.64	163300.5	200366.8	PLUGGED	163300.5	130640
42	63617.2	104276.5	103426	103426	82740.8	167043.2	207702.5	PLUGGED	167043.2	133635
43	63617.2	107889.7	107189.6	107189.6	85751.68	170806.9	215079.3	PLUGGED	170806.9	136646
44	63617.2	111522.6	110974	110974	88779.2	174591.2	222496.6	PLUGGED	174591.2	139673
45	63617.2	115175.1	114778.6	114778.6	91822.88	178395.9	229953.7	PLUGGED	178395.9	142717
46	63617.2	118846.7	118603.2	118603.2	94882.56	182220.5	237449.9	PLUGGED	182220.5	145776
47	63617.2	122537.2	122447.5	122447.5	97958	186064.8	244984.8	PLUGGED	186064.8	148852
48	63617.2	126246.4	126311.2	126311.2	101048.96	189928.5	252557.6	PLUGGED	189928.5	151943
49	63617.2	129973.8	130194	130194	104155.2	193811.2	260167.8	PLUGGED	193811.2	155049
50	63617.2	133719.4	134095.6	134095.6	107276.48	197712.8	267815	PLUGGED	197712.8	158170
										0

PILE DRIVING ASSESSMENT
Pile Sizing Calculations

CATHIE ASSOCIATES

DCB_BE_7MW Loads

Requirement

Pile Diameter	Jacket	
	Compress (MN)	Tension (MN)
2m	38.71	29.51
3m	38.71	29.51

Results

Pile Diameter	Required Pile Length	Capacity		Utilisation		Hammer Type/Size
		Compress	Tens	Compress	Tens	
2m	32	61.79	31.93	0.63	0.92	
3m	27	64.54	30.34	0.60	0.97	

1.25 resistance factor applied to soil resistances (DNV-OS-J101)

2m Pile Diameter

Final Pen (m)	End Capacity Plugged (kN)	End Capacity Unplug (kN)	Cum Friction Compres (kN)	Cum Friction Tension (kN)	Factored Tension (kN)	Total Capacity Plugged (kN)	Total Capacity Unplugged (kN)	Plugged/Unplu	Total Capacity (kN)	Factored Total Capacity (kN)
0	0	0	0	0	0	0	0	PLUGGED	0	0
3	0	0	0	0	0	0	0	PLUGGED	0	0
3	4147	516	36	36	28.6	4182.7	552	UNPLUGGED	552	442
4	5529	782	147	147	117.984	5676.7	930	UNPLUGGED	930	744
5	6912	1078	291	291	232.912	7202.6	1369	UNPLUGGED	1369	1095
6	7741	1270	393	393	314.12	8133.5	1663	UNPLUGGED	1663	1330
7	8998	1637	627	627	501.648	9624.6	2264	UNPLUGGED	2264	1811
7	9500	1793	731	731	584.544	10230.9	2523	UNPLUGGED	2523	2019
8	10757	2206	1014	1014	811.52	11771.2	3220	UNPLUGGED	3220	2576
9	12014	2652	1333	1333	1066.56	13346.7	3985	UNPLUGGED	3985	3188
10	13270	3131	1687	1687	1349.84	14957.4	4818	UNPLUGGED	4818	3854
11	14527	3643	2077	2077	1661.28	16603.3	5720	UNPLUGGED	5720	4576
12	15783	4188	2501	2501	2000.8	18284.4	6689	UNPLUGGED	6689	5351
13	17040	4767	2961	2961	2368.56	20000.7	7727	UNPLUGGED	7727	6182
14	18297	5378	3456	3456	2764.48	21752.2	8834	UNPLUGGED	8834	7067
15	19553	6023	3986	3986	3188.48	23538.9	10008	UNPLUGGED	10008	8006
16	20810	6700	4551	4551	3640.72	25360.8	11251	UNPLUGGED	11251	9001
17	22067	7411	5151	5151	4121.04	27217.9	12562	UNPLUGGED	12562	10050
18	23323	8155	5787	5787	4629.6	29110.2	13942	UNPLUGGED	13942	11153
19	24580	8931	6458	6458	5166.24	31037.6	15389	UNPLUGGED	15389	12311
20	25837	9741	7164	7164	5731.12	33000.3	16905	UNPLUGGED	16905	13524
21	34212	13022	9617	9617	7693.28	43828.5	22639	UNPLUGGED	22639	18111
22	34495	15411	12123	12123	9698.32	46617.6	27534	UNPLUGGED	27534	22027
23	34777	17849	14682	14682	11745.28	49459	32530	UNPLUGGED	32530	26024
24	35060	20335	17291	17291	13833.12	52351.6	37626	UNPLUGGED	37626	30101
25	35343	22868	19952	19952	15961.2	55294.4	42820	UNPLUGGED	42820	34256
26	35626	25448	22661	22661	18128.64	58286.5	48109	UNPLUGGED	48109	38487
27	35908	28073	25419	25419	20334.88	61327	53492	UNPLUGGED	53492	42794
28	36191	30743	28224	28224	22579.28	64415.3	58968	UNPLUGGED	58968	47174
29	36474	33458	31077	31077	24861.36	67550.6	64534	UNPLUGGED	64534	51628
30	36757	36216	33976	33976	27180.48	70732.3	70191	UNPLUGGED	70191	56153
31	37039	39017	36920	36920	29536.32	73959.8	75937	PLUGGED	73960	59168
32	37322	41860	39910	39910	31928.32	77232.6	81771	PLUGGED	77233	61786
33	37605	44746	42945	42945	34356.16	80550.1	87691	PLUGGED	80550	64440
34	37888	47673	46024	46024	36819.52	83912	93697	PLUGGED	83912	67130
35	38170	50642	49147	49147	39317.92	87317.7	99789	PLUGGED	87318	69854
36	38453	53651	52314	52314	41851.04	90766.9	105965	PLUGGED	90767	72614
37	38736	56701	55523	55523	44418.72	94259.3	112224	PLUGGED	94259	75407
38	39019	59791	58776	58776	47020.64	97794.4	118567	PLUGGED	97794	78236
39	39301	62921	62071	62071	49656.4	101371.9	124992	PLUGGED	101372	81098
40	39584	66091	65407	65407	52325.92	104991.5	131498	PLUGGED	104992	83993
41	39867	69299	68786	68786	55028.88	108652.9	138086	PLUGGED	108653	86922
42	40150	72547	72206	72206	57765.04	112355.9	144754	PLUGGED	112356	89885
43	40432	75834	75668	75668	60534.24	116100.1	151502	PLUGGED	116100	92880
44	40715	79159	79170	79170	63336.32	119885.4	158330	PLUGGED	119885	95908
45	40998	82523	82714	82714	66170.96	123711.5	165237	PLUGGED	123712	98969
46	41281	85925	86298	86298	69038.08	127578.1	172222	PLUGGED	127578	102062
47	41563	89365	89922	89922	71937.52	131485.2	179287	PLUGGED	131485	105188
48	41846	92842	93586	93586	74869.12	135432.4	186428	PLUGGED	135432	108346
49	42129	96357	97291	97291	77832.64	139419.6	193648	PLUGGED	139420	111536
50	42412	99910	101035	101035	80828	143446.5	200945	PLUGGED	143447	114757
										0

3m Pile Diameter

Final Pen (m)	End Capacity Plugged (kN)	End Capacity Unplug (kN)	Cum Friction Compres (kN)	Cum Friction Tension (kN)	Factored Tension (kN)	Total Capacity Plugged (kN)	Total Capacity Unplugged (kN)		Total Capacity (kN)	Factored Total Capacity (kN)
0.1	0	0	0	0	0	0	0	PLUGGED	0	
3.9	0	0	0	0	0	0	0	PLUGGED	0	0
4	12440.7	993.51	18.91	18.91	15.128	12459.6	1012.4	UNPLUGGED	1012.4	810
5	15550.9	1444.2	234.39	234.39	187.512	15785.3	1678.6	UNPLUGGED	1678.6	1343
5.6	17417	1736.7	386.67	386.67	309.336	17803.7	2123.4	UNPLUGGED	2123.4	1699
6.6	20244.4	2295.9	738.28	738.28	590.624	20982.7	3034.2	UNPLUGGED	3034.2	2427
7	21375.4	2533.8	893.7	893.7	714.96	22269.1	3427.5	UNPLUGGED	3427.5	2742
8	24202.8	3164	1319.2	1319.2	1055.36	25522.1	4483.2	UNPLUGGED	4483.2	3587
9	27030.3	3844.8	1797.5	1797.5	1438	28827.8	5642.4	UNPLUGGED	5642.4	4514
10	29857.7	4576.4	2328.7	2328.7	1862.96	32186.4	6905	UNPLUGGED	6905	5524
11	32685.1	5358.6	2912.6	2912.6	2330.08	35597.7	8271.1	UNPLUGGED	8271.1	6617
12	35512.6	6191.5	3549.3	3549.3	2839.44	39061.8	9740.7	UNPLUGGED	9740.7	7793
13	38340	7075.1	4238.8	4238.8	3391.04	42578.8	11313.8	UNPLUGGED	11313.8	9051
14	41167.4	8009.3	4981	4981	3984.8	46148.5	12990.4	UNPLUGGED	12990.4	10392
15	43994.9	8994.3	5776.1	5776.1	4620.88	49771	14770.4	UNPLUGGED	14770.4	11816
16	46822.3	10029.9	6624	6624	5299.2	53446.3	16653.9	UNPLUGGED	16653.9	13323
17	49649.7	11116.2	7524.7	7524.7	6019.76	57174.4	18640.9	UNPLUGGED	18640.9	14913
18	52477.2	12253.2	8478.1	8478.1	6782.48	60955.3	20731.4	UNPLUGGED	20731.4	16585
19	55304.6	13440.9	9484.4	9484.4	7587.52	64789	22925.3	UNPLUGGED	22925.3	18340
20	58132	14679.3	10543.5	10543.5	8434.8	68675.5	25222.7	UNPLUGGED	25222.7	20178
21	76976.9	19688.7	14222.6	14222.6	11378.08	91199.5	33911.3	UNPLUGGED	33911.3	27129
22	77613	23347.6	17982.1	17982.1	14385.68	95595.1	41329.7	UNPLUGGED	41329.7	33064
23	78249.2	27082	21820	21820	17456	100069.3	48902	UNPLUGGED	48902	39122
24	78885.4	30890	25734.8	25734.8	20587.84	104620.2	56624.9	UNPLUGGED	56624.9	45300
25	79521.6	34770.4	29724.9	29724.9	23779.92	109246.5	64495.3	UNPLUGGED	64495.3	51596
26	80157.7	38721.7	33788.9	33788.9	27031.12	113946.6	72510.6	UNPLUGGED	72510.6	58008
27	80793.9	42742.8	37925.6	37925.6	30340.48	118719.5	80668.5	UNPLUGGED	80668.5	64535
28	81430.1	46832.7	42133.9	42133.9	33707.12	123564	88966.6	UNPLUGGED	88966.6	71173
29	82066.3	50990.2	46412.7	46412.7	37130.16	128479	97403	UNPLUGGED	97403	77922
30	82702.4	55214.6	50761.2	50761.2	40608.96	133463.6	105975.7	UNPLUGGED	105975.7	84781
31	83338.6	59504.9	55178.3	55178.3	44142.64	138516.9	114683.2	UNPLUGGED	114683.2	91747
32	83974.8	63860.4	59663.3	59663.3	47730.64	143638.1	123523.8	UNPLUGGED	123523.8	98819
33	84610.9	68280.4	64215.6	64215.6	51372.48	148826.5	132496	UNPLUGGED	132496	105997
34	85247.1	72764.2	68834.2	68834.2	55067.36	154081.3	141598.5	UNPLUGGED	141598.5	113279
35	85883.3	77311.2	73518.7	73518.7	58814.96	159402	150830	UNPLUGGED	150830	120664
36	86519.5	81920.8	78268.5	78268.5	62614.8	164787.9	160189.3	UNPLUGGED	160189.3	128151
37	87155.6	86592.5	83082.8	83082.8	66466.24	170238.5	169675.4	UNPLUGGED	169675.4	135740
38	87791.8	91325.8	87961.4	87961.4	70369.12	175753.2	179287.1	PLUGGED	175753.2	140603
39	88428	96120.1	92903.5	92903.5	74322.8	181331.5	189023.6	PLUGGED	181331.5	145065
40	89064.1	100975.1	97908.8	97908.8	78327.04	186972.9	198883.8	PLUGGED	186972.9	149578
41	89700.3	105890.2	102976.8	102976.8	82381.44	192677.1	208867.1	PLUGGED	192677.1	154142
42	90336.5	110865.2	108107.2	108107.2	86485.76	198443.7	218972.4	PLUGGED	198443.7	158755
43	90972.7	115899.7	113299.4	113299.4	90639.52	204272.1	229199.1	PLUGGED	204272.1	163418
44	91608.8	120993.2	118553.2	118553.2	94842.56	210162.1	239546.5	PLUGGED	210162.1	168130
45	92245	126145.5	123868.2	123868.2	99094.56	216113.2	250013.8	PLUGGED	216113.2	172891
46	92881.2	131356.2	129244.1	129244.1	103395.28	222125.3	260600.3	PLUGGED	222125.3	177700
47	93517.4	136625.1	134680.5	134680.5	107744.4	228197.9	271305.6	PLUGGED	228197.9	182558
48	94153.5	141951.8	140177.2	140177.2	112141.76	234330.8	282129	PLUGGED	234330.8	187465
49	94789.7	147336	145733.9	145733.9	116587.12	240523.6	293069.9	PLUGGED	240523.6	192419
50	95425.9	152777.6	151350.2	151350.2	121080.16	246776.1	304127.8	PLUGGED	246776.1	197421
					0					0
										0

Appendix C

Piling Driveability Assessment Results

PILE DRIVING ASSESSMENT

Pile Driveability Calculations

Client : Seagreen
Project : Round 3 Firth of Forth Phase 1
Project No : C162

Revision History

Revision	Purpose	Date	Author	Checked	Reviewed
0	For Comment	06/03/2002	VTE	MRO	JIR

C162 - Seagreen Round 3 Firth of Forth Phase 1 Development Zone
Additional Pile Driveability Assessment including variable efficiency and drive-drill drive mode
Pile Driving Mode Results

				Axial Capacity					Pile Driveability Assessment									
Scenario	Pile Diameter	Required		Achieved Capacity			Utilisation		Max SRD (kN)	Hammer Size	Driveability Results			Total Blow Count	Duration*	Enthru (kJ)		Comment/Assumptions
		Comp (MN)	Ten (MN)	Required Pile Length (m)	Comp (MN)	Ten (MN)	Compress	Tens			Driveable Pile Length (m)	Max Comp (MPa)	Max Ten (MPa)		(Hour)	Min (15%)	Max (95%)	
MCB_BE	2m	34.07	25.97	27	51.80	27.10	0.66	0.96	78504	IHC-S1800	27	235.23	-24.10	2316	0.9	233	1420	Plugged at 24m
MCB_BE	3m	34.07	25.97	22	55.97	26.52	0.61	0.98	61027	IHC-S1800	22	198.47	-31.81	1329	0.5	231	1436	Unplugged driving
MCB_UB	2m	34.07	25.97	25	57.28	27.84	0.59	0.93	90766	IHC-S2300	25	248.68	-32.55	1553	0.6	327	2056	Pluugged at 25m
MCB_UB	3m	34.07	25.97	21	60.80	28.43	0.56	0.91	67648	IHC-S2300	21	211.21	-27.33	893	0.3	333	2081	Unplugged driving
DCB_BE	2m	34.07	25.97	32	49.42	26.80	0.69	0.97	78083	IHC-S1800	32	233.78	-27.32	2381	0.9	233	1432	Plugged at 30m
DCB_BE	3m	34.07	25.97	27	55.00	26.06	0.62	1.00	56647	IHC-S1800	27	196.36	-38.32	1406	0.5	231	1449	Unplugged driving
DCB_UB	2m	34.07	25.97	30	56.15	27.18	0.61	0.96	58340	IHC-S1800	30	229.75	-27.07	1597	0.6	233	1445	Unplugged driving
DCB_UB	3m	34.07	25.97	26	58.00	27.00	0.59	0.96	63156	IHC-S1800	26	196.98	-39.51	1393	0.5	231	1446	Unplugged driving
DCB_UB_7MW	2m	38.71	29.51	32	61.79	31.93	0.63	0.92	66668	IHC-S2300	<32	n/a						**Refusal in plugged mode at 30m BSBL**
DCB_UB_7MW	3m	38.71	29.51	27	64.54	30.34	0.59	0.96	69190	IHC-S1800	27	197.50	-58.60	1421	0.5	231	1449	Unplugged driving

*Does not include changes in hammer efficiency , helmets etc and assumes a continous driving process at 45blows/min

C162 - Seagreen Round 3 Firth of Forth Phase 1 Development Zone
Additional Pile Driveability Assessement
Pile Driving Mode

Ground Model	Parameter Model	Pile Diameter (m)	Pile Length (m)	Hammer Model	Efficiency (%)	Depth(m)	SRD (kN)	Blows per meter	Compression (MPa)	Tension (MPa)	Energy (kJ)	Cumulative Blowcount
MCB	BE	2	27	IHC S1800	15%	0.0	2000	0	0	0	0	0
					15%	6.0	4000	26	86	-51	233	77
					15%	10.0	5000	33	86	-46	233	195
					15%	11.5	5200	35	86	-45	233	246
					35%	14.5	14539	72	122	-31	411	405
					55%	17.5	24205	80	155	-25	644	632
					75%	22.5	40649	87	203	-29	1143	1047
					95%	23.5	70782	228	234	-26	1428	1205
					95%	25.5	74626	274	235	-25	1425	1707
					95%	27.0	78504	335	235	-24	1421	2316
MCB	BE	3	22	IHC S1800	15%	0.0	470	0	0	0	0	0
					15%	1.5	1377	0	0	0	0	0
					15%	3.5	3031	21	73	-57	231	21
					15%	6.1	4915	33	74	-51	231	90
					15%	8.5	7827	55	74	-42	230	196
					35%	11.5	17552	64	116	-37	537	375
					55%	13.6	31502	81	148	-25	840	527
					75%	16.5	46152	92	174	-23	1139	778
					95%	19.5	51085	84	197	-27	1441	1042
					95%	22.0	61027	107	198	-32	1436	1329
MCB	UB	2	25	IHC S2300	15%	3.5	912	0	0	0	0	0
					15%	6.8	2723	14	88	-46	327	23
					15%	10.5	5504	26	89	-30	328	97
					15%	12.7	10575	53	89	-19	330	184
					35%	15.5	21337	53	138	-13	780	332
					35%	18.5	33084	93	139	-13	775	550
					55%	21.5	45055	96	177	-18	1214	833
					75%	23.5	53161	91	208	-23	1653	1019
					95%	24.5	88347	308	247	-33	2060	1219
					95%	25.0	90766	361	249	-33	2056	1553
MCB	UB	3	21	IHC S2300	15%	3.5	1377	0	0	0	0	0
					15%	6.1	3467	16	79	-49	333	21
					15%	7.5	4806	21	79	-44	333	48
					15%	9.5	7035	33	79	-37	333	102
					15%	12.1	10474	51	79	-26	333	211
					35%	13.6	21079	53	123	-13	778	289
					35%	15.5	32067	82	124	-17	780	416
					55%	17.5	43778	77	158	-25	1218	575
					75%	19.5	55638	79	186	-25	1653	731
					95%	21.0	67648	83	211	-27	2081	893
DCB	BE	2	32	IHC S1800	15%	7.5	2710.0	20	86	-65	233	75
					15%	10.5	4509.0	29	86	-58	232	149
					15%	13.5	6720.00	44	86	-48	230	258
					15%	16.5	9343	61	86	-38	229	415
					15%	19.5	12377	88	87	-29	224	639
					35%	22.5	21388	72	136	-35	530	879
					55%	25.5	31130	73	172	-29	829	1096
					75%	28.5	41060	88	202	-25	1144	1337
					95%	29.5	72083.0	247	233	-24	1436	1505
					95%	32.0	78083.0	337	234	-27	1432	2381
DCB	BE	3	27	IHC S1800	15%	3.5	1500	0	0	0	0	0
					15%	6.1	3031	21	73	-61	231	27
					15%	7.5	4082	28	74	-57	231	61
					15%	10.5	6788	48	74	-49	230	174
					15%	13.5	10110	74	74	-40	230	357
					35%	16.5	14050	51	116	-55	539	544
					35%	19.5	18607	71	116	-41	538	726
					55%	22.5	32134	82	147	-29	844	955
					75%	25.5	46747	93	173	-33	1146	1217
					95%	27.0	56647	96	196	-38	1449	1406
DCB	UB	2	30	IHC S1800	15%	5.3	1640	0	0	0	0	0
					15%	6.8	2453	19	86	-61	233	15
					15%	9.5	4303	29	86	-51	233	79
					15%	12.5	6878	48	86	-38	232	194
					15%	15.5	10007	73	86	-25	232	376
					35%	18.5	13691	50	134	-30	542	561
					35%	21.5	22418	84	135	-12	538	761
					75%	25.5	38070	81	201	-32	1147	1089
					95%	28.5	50138	100	229	-27	1448	1360
					95%	30.0	58340	137	230	-27	1445	1597
DCB	UB	3	26	IHC S1800	15%	5.3	2473	0	0	0	0	0
					15%	6.8	3697	25	73	-58	231	19
					15%	9.5	6478	46	74	-49	230	115
					15%	12.5	10347	75	74	-38	230	296
					15%	15.5	15047	55	116	-51	539	491
					35%	18.5	20580	81	116	-35	538	694
					35%	21.5	33689	85	147	-28	843	943
					75%	24.5	51228	84	196	-36	1449	1198
					95%	25.5	57168	97	197	-39	1448	1288
					95%	26.0	63155	112	197	-40	1446	1393
DCB_7MW	UB	2	32 (plugged)	IHC S2300	Refusal at approximately 30m below mudline							
DCB_7MW	UB	3	27	IHC S1800	15%	5.3	2473	0	0	0	0	0
					15%	6.8	3697	25	73	-59	231	19
					15%	9.5	6478	46	74	-50	230	115
					15%	12.5	10347	75	74	-39	230	297
					35%	15.5	15047	55	116	-52	539	492
					35%	18.5	20580	81	116	-35	538	695
					55%	21.5	33690	85	147	-30	843	945
					75%	23.5	45335	90	173	-32	1146	1120
					95%	25.5	57168	97	196	-38	1449	1307
					95%	26.5	69190	131	197	-37	1445	1421

C162 - Seagreen Round 3 Firth of Forth Phase 1 Development Zone
Additional Pile Driveability Assessment including variable efficiency and drive-drill drive mode
Drive Drill Drive Mode Results

				Axial Capacity					Pile Driveability Assessment											
Scenario	Pile Diameter	Required		Achieved Capacity			Utilisation		Max SRD (kN)	Hammer Size	Driveability Results			Total Blow Count	Duration	Duration*	Enthru (kJ)		Comment
		Comp (MN)	Ten (MN)	Required Pile Length (m)	Comp (MN)	Ten (MN)	Compress	Tens			Drilled section (m below mudline)	Max Comp (MPa)	Max Ten (MPa)		(Min)	(Hour)	Min (15%)	Max (75%)	
MCB_BE	2m	34.07	25.97	29	34.35	31.48	0.99	0.82	40837	IHC S1200	17	190.28	-63.58	1445	32	0.5	189	916	See report for assumptions adopted .
MCB_BE	3m	34.07	25.97	24	35.74	31.75	0.95	0.82	40293	IHC S1200	12	161.02	-59.45	1362	30	0.5	186	920	See report for assumptions adopted .
MCB_UB	2m	34.07	25.97	27	35.91	32.44	0.95	0.80	40773	IHC S1200	15	190.49	-64.65	1351	30	0.5	189	915	See report for assumptions adopted .
MCB_UB	3m	34.07	25.97	22	36.74	31.64	0.93	0.82	48956	IHC S1200	10	161.36	-58.78	1081	24	0.4	187	919	See report for assumptions adopted .
DCB_BE	2m	34.07	25.97	35	35.20	32.60	0.97	0.80	39397	IHC S1200	15	182.74	-54.74	2061	46	0.8	176	870	See report for assumptions adopted .
DCB_BE	3m	34.07	25.97	29	35.56	31.57	0.96	0.82	46347	IHC S1200	9	154.81	-54.69	1746	39	0.6	175	870	See report for assumptions adopted .
DCB_UB	2m	34.07	25.97	32	35.40	31.90	0.96	0.81	40323	IHC S1200	12	182.90	-58.91	1802	40	0.7	177	869	See report for assumptions adopted .
DCB_UB	3m	34.07	25.97	27	35.41	30.34	0.96	0.86	47722	IHC S1200	7	154.90	-58.09	1662	37	0.6	175	869	See report for assumptions adopted .
DCB_UB_7MW	2m	38.71	29.51	34	40.35	36.80	0.96	0.80	45580	IHC S1200	14	206.89	-50.39	2062	46	0.8	176	1100	Max energy quoted is at 95% efficiency
DCB_UB_7MW	3m	38.71	29.51	29	42.28	37.13	0.92	0.79	55619	IHC S1200	9	175.19	-53.54	2199	49	0.8	175	1099	Max energy quoted is at 95% efficiency

C162 - Seagreen Round 3 Firth of Forth Phase 1 Development Zone
Additional Pile Driveability Assessement
Drive_Drill_Drive Mode

Ground Model	Parameter Model	Pile Diameter (m)	Pile Length (m)	Hammer Model	Efficiency (%)	Depth(m)	SRD (kN)	Blows per meter	Compression (MPa)	Tension (MPa)	Energy (kJ)	Cumulative Blowcount
MCB	BE	2	29	IHC S1200	15%	7.5	3263.9	24	80	-64	189	89
					15%	9.5	4509.4	34	80	-59	188	146
					15%	11.5	5632	43	80	-55	188	223
					35%	12.7	14079	52	126	-59	435	280
					35%	14.5	11345	41	126	-68	437	364
					35%	17.5	16676	65	126	-51	434	524
					35%	20.5	22311	85	126	-40	431	750
					55%	23.5	28227	72	161	-43	677	985
					55%	26.5	34407	90	162	-35	673	1228
					75%	29.0	40837	84	190	-32	916	1445
MCB	BE	3	24	IHC S1200	15%	6.8	3533	29	68	-59	186	97
					15%	9.5	5818	47	68	-54	186	199
					15%	11.5	7827	66	68	-50	186	313
					35%	12.7	18417	91	107	-52	432	407
					35%	14.5	21660	71	107	-60	433	553
					35%	16.5	17765	96	107	-49	431	719
					55%	18.5	23206	79	136	-59	679	894
					55%	20.5	28780	90	136	-50	677	1063
					75%	22.5	34478	80	161	-53	922	1233
					75%	24.0	40293	91	161	-50	920	1362
MCB	UB	2	27	IHC S1200	15%	6.8	2723	21	80	-65	189	70
					15%	9.5	4671	35	80	-57	188	146
					15%	12.1	6958	54	80	-48	187	261
					35%	13.6	16779	66	126	-44	433	351
					35%	14.5	11447	42	126	-64	437	399
					35%	16.5	15494	59	126	-49	434	500
					35%	19.5	21904	85	127	-35	431	717
					55%	22.5	28691	75	161	-40	675	957
					55%	25.5	35829	97	162	-34	671	1215
					75%	27.0	40773	85	190	-35	915	1351
MCB	UB	3	22	IHC S1200	15%	6.1	3467	26	68	-59	187	78
					15%	9.5	7035	57	68	-50	186	270
					15%	11.5	9633	79	68	-45	185	455
					15%	12.1	10473	86	68	-43	185	519
					55%	13.6	30400	83	136	-47	678	564
					55%	15.5	24200	67	136	-62	679	515
					55%	17.5	30939	84	136	-46	678	736
					55%	19.5	37953	100	137	-44	676	974
					75%	21.5	45226	91	161	-47	920	975
					75%	22.0	48956	98	161	-47	919	1081
DCB	BE	2	35	IHC S1200	15%	12.5	5938	50	77	-55	176	313
					15%	17.5	10309	92	78	-42	175	667
					35%	19.5	12377	49	121	-67	411	808
					35%	21.5	20760	82	122	-48	408	939
					35%	23.5	15874	67	122	-59	409	1088
					35%	25.5	19647	79	122	-50	408	1234
					35%	27.5	23483	93	122	-42	407	1406
					55%	30.5	29348	78	155	-47	640	1662
					55%	33.5	35338	98	155	-35	638	1925
					75%	35.0	39397	83	183	-39	870	2061
DCB	BE	3	29	IHC S1200	15%	9.5	5818	51	65	-55	175	244
					15%	12.5	8935	81	65	-49	174	442
					35%	15.5	12669	54	103	-74	409	645
					35%	18.5	17020	73	103	-64	408	836
					35%	19.5	18607	81	103	-61	408	914
					55%	21.5	36391	98	131	-51	639	1092
					55%	23.5	27862	79	131	-64	641	1269
					55%	25.5	33928	92	131	-53	639	1440
					75%	27.5	40091	82	155	-56	871	1614
					75%	29.0	46347	94	155	-47	870	1746
DCB	UB	2	32	IHC S1200	15%	9.5	4303	35	77	-59	177	164
					15%	12.5	6878	57	77	-49	176	301
					15%	15.5	10007	87	78	-39	175	516
					35%	18.5	13691	55	122	-57	410	728
					35%	19.5	15042	62	122	-53	409	787
					35%	21.5	24239	98	122	-38	407	946
					35%	23.5	18554	77	122	-45	408	1121
					55%	26.5	25456	69	155	-47	640	1340
					55%	29.5	32717	90	155	-34	638	1580
					75%	32.0	40323	88	183	-32	869	1802
DCB	UB	3	27	IHC S1200	15%	6.8	3697	31	65	-58	175	106
					15%	9.5	6478	57	65	-53	175	225
					15%	12.5	10347	94	65	-45	174	452
					35%	15.5	15047	64	103	-66	408	688
					35%	18.5	20580	93	103	-53	407	924
					35%	19.5	22608	99	103	-49	407	1020
					75%	21.5	42590	89	155	-48	870	1208
					75%	23.5	32677	71	154	-63	873	1368
					75%	25.5	40072	84	155	-50	871	1524
					75%	27.0	47722	100	155	-43	869	1662
DCB_7MW	UB	2	34	IHC S1200	15%	12.5	6878	57	77	-50	176	356
					15%	15.5	10007	88	78	-41	175	572
					35%	18.5	13691	55	121	-61	410	786
					35%	19.5	15042	62	122	-58	410	845
					35%	21.5	24239	97	122	-40	407	1004
					35%	23.5	18554	76	122	-49	408	1177
					55%	26.5	25456	68	155	-51	641	1393
					55%	29.5	32717	89	155	-36	638	1629
					75%	32.5	40323	87	183	-33	869	1893
					95%	34.5	45580	82	207	-35	1100	2062
DCB_7MW	UB	3	29	IHC S1200	15%	12.5	6478	58	65	-54	175	361
					15%	15.5	10347	94	65	-46	174	589
					35%	18.5	15047	64	103	-68	408	827
					35%	19.5	20580	92	103	-57	407	905
					35%	21.5	22608	97	103	-53	407	1094
					75%	23.5	42590	87	155	-53	871	1278
					75%	26.5	32677	70	154	-71	873	1512
					75%	29.5	40072	82	155	-56	871	1740
					75%	32.5	47722	97	155	-45	870	2009
					95%	34.5	55619	93	175	-44	1099	2199