Contents

1. Scope of Work

The scope of work of the following calculation includes the design and verification of all relevant load combinations applicable to the foundations of the Inverter Stations (MVPs) at Dunfermline Project. The Inverter Stations will be placed directly on top of the proposed foundation.

It is important to note that a worst-case scenario philosophy was adopted for the design of this particular Foundation Design, due to the complex soil and environmental conditions present on site. This approach results in safer design and is characterized by always assuming the worst-case scenario when it comes to both the material and site properties as well as the applicable loading combinations.

1. MVPs Specification

The full specification of the Inverter Station is shown in Appendix A and can be summarized (only essential information) as follows:

- Weight: <18tonnes, divided into 3 strips with 2 column loads each resulting in a 30kN, however due to SMA recommendations we will use a value of 55kN (5400kg).
- Dimensions: 2438x6058x2896mm.
- Grounding: shown on the drawings.

2. Relevant Standards

- BS EN 1991-1-3:2005 (Eurocode 1 – Part 3): Snow Loads + UK National Annex;
- BS EN 1991-1-4:2008 (Eurocode 1 – Part 4): Wind Actions;
- BS EN 1992:2004 (Eurocode 2): Design of concrete structures;

- BS EN 1997-1:2004, Geotechnical design ‑ Part 1: General rules.
- NA to BS EN 1991-1-4:2005+A1:2010, National Annex to BS EN 1991-1-1-4:2005,
- Eurocode 1 ‑ Actions on structures. Part 1-4: General actions ‑ Wind actions.
- Eurocode 7 – Geotechnical Design.

2. Introduction

3. Design Proposal

The current design solution proposal includes the usage of three (3) identical pre cast pad foundations of size 2900x500x500mm, including a r50 chamfer on the top surface to help mitigate concrete wear and damage. The pre cast concrete blocks will be placed on top of a 1100mm deep Type 1 Unbound Aggregate (803 (DMRB)) layer on top of a readily available geotextile (>200g/m^2), covered with a very thin layer of sand (<50mm), to protect the geotextile from perforation coming from the crushed coarse aggregate on top. This design methodology is suitable for particular site conditions and allows fast, easy and economically feasible solution for the Inverter Station installation on site.

4. Geotechnical Information

The site conditions on Dunfermline Project can be summarized as non-standard or with elevated complexity. For the full Dunfermline North Solar Farm Geotechnical Site Investigation 355577-R01(02) RSK Report please refer to the previously submitted documents. In general the following ground conditions are present on site:

> The made ground generally comprised predominantly cohesive soils interspersed with granular pockets and ranged in thickness from 0.20 m to >5.00 m. It has been assumed that the back filling of the quarry will have been engineered to a degree. The made ground encountered on site can be generally grouped into the following sub-strata:
>
> - firm to stiff dark grey sandy gravelly CLAY with low to moderate cobble content. Gravel is angular to subangular fine to coarse of mixed sandstone and mudstone lithics and coal-like fragments;

- loose light yellowish grey gravelly medium to coarse SAND with low cobble content. Gravel is subangular fine to coarse of extremely weak light yellowish grey sandstone. Sporadic pockets of black gravelly clay; and
- dense grey black gravelly fine to coarse SAND with low cobble content. Gravel is subangular fine to coarse of mixed mudstone, sandstone and coal fragments.

Common anthropogenic materials observed within made ground strata were brick and ceramic fragments.

A summary of the in-situ and laboratory test results recorded in the stratum are presented in Table 11.

Table 11 Summary of in-situ and laboratory test results for made ground

<table>
<tr><th colspan="2">Soil parameters</th><th>Min. Value</th><th>Max. Value</th><th>Average</th></tr>
<tr><td colspan="5">Cohesive soils</td></tr>
<tr><td colspan="2">Moisture content (%)</td><td>13.2</td><td>32.1</td><td>17.7</td></tr>
<tr><td colspan="2">Liquid limit (%)</td><td>29.0</td><td>38.0</td><td>32.7</td></tr>
<tr><td colspan="2">Plasticity limit (%)</td><td>15.0</td><td>19.0</td><td>16.2</td></tr>
<tr><td colspan="2">Plasticity index (%)</td><td>14.0</td><td>19.0</td><td>16.5</td></tr>
<tr><td colspan="2">Modified plasticity index (%)</td><td>8.8</td><td>16.2</td><td>12.0</td></tr>
<tr><td colspan="2">Plasticity term</td><td>Low</td><td>Intermediate</td><td>-</td></tr>
<tr><td colspan="2">Volume change potential</td><td colspan="3">Low</td></tr>
<tr><td rowspan="5">Grading (%)</td><td>Cobble</td><td colspan="3">0</td></tr>
<tr><td>Gravel</td><td>6.0</td><td>28.0</td><td>18.0</td></tr>
<tr><td>Sand</td><td>28.0</td><td>48.0</td><td>37.0</td></tr>
<tr><td>Silt</td><td>14.0</td><td>31.0</td><td>25.0</td></tr>
<tr><td>Clay</td><td>16.0</td><td>22.0</td><td>20.0</td></tr>
<tr><td rowspan="2">Small Shearbox</td><td>Effective Cohesion - c' (kN/m^2)</td><td colspan="3">22</td></tr>
<tr><td>Effective angle of shear resistance - ϕ' (degrees)</td><td colspan="3">38</td></tr>
<tr><td>Triaxial</td><td>Bulk Density (Mg/m^3)</td><td>2.06</td><td>2.13</td><td>2.09</td></tr>
</table>

(remoulded – 2.5kg rammer)	Dry Density (Mg/m^3)	1.79	1.87	1.82

Soil parameters		Min. Value	Max. Value	Average
	Undrained Shear Stress (kN/m^2)*	29	97	58.8
Consolidation	Bulk Density (Mg/m^3)	1.72	2.06	1.90
	Dry Density (Mg/m^3)	1.43	1.85	1.61
	Voids Ratio**	0.41	0.73	0.58
	Coefficient of compressibility (m^2/MN)**	0.11	0.92	0.57
	Coefficient of consolidation ($m^2/year$)**	4.50	25.21	50.56
Remoulded CBR (%)		0.40	10.00	3.83
Compaction (2.5 kg rammer)	Optimum moisture content (%)	11.20	15.30	13.43
	Maximum dry density (Mg/m^3)	1.76	1.90	1.84
SPT 'N' values		2	>50	17.8
Undrained shear strength inferred from SPT 'N' values (kN/m^2)***		9	>225	80.1
Undrained shear strength measured by shear vane testing (kN/m^2)		56	>120	87.7
Consistency term from field description		Very soft	Very stiff	-
Consistency term inferred from remoulded triaxials		Soft	Stiff	
Granular soils				
Moisture content (%)		7.9	13.1	10.5
Liquid limit (%)		27.0	28.0	27.5
Plasticity limit (%)		Non-plastic	15.0	-
Plasticity index (%)		Non-plastic	13.0	-

Grading (%)	Cobble	0		
	Gravel	13.0	35.0	24.0
	Sand	44.0	58.0	51.0
	Silt	10.0	13.0	12.0
	Clay	11.0	16.0	14.0
Remoulded CBR (%)		1.80		
Triaxial (remoulded – 2.5kg rammer)	Bulk Density (Mg/m^3)	2.03	2.09	2.06
	Dry Density (Mg/m^3)	1.81	1.83	1.82
	Undrained Shear Stress (kN/m^2)*	62.0	103.0	82.5
Consolidation	Bulk Density (Mg/m^3)	1.77	1.94	1.86
	Dry Density (Mg/m^3)	1.57	1.60	1.59
Soil parameters		**Min. Value**	**Max. Value**	**Average**
	Voids Ratio**	0.55	0.58	0.56
	Coefficient of compressibility (m^2/MN)**	0.47	0.84	0.65
	Coefficient of consolidation ($m^2/year$)**	4.35	4.63	4.49
Small Shearbox	Effective Cohesion - c' (kN/m^2)	4.0	11.0	7.5
	Effective angle of shear resistance - ϕ' (degrees)	33.0	39.0	36.0
Compaction testing (2.5 kg rammer)	Optimum moisture content (%)	10.2		
	Maximum dry density (Mg/m^3)	1.92		
SPT 'N' values		2	43	20.3
Density term inferred from SPT		Very loose	Dense	Medium dense

Notes:

*cell pressure of 20 kN/m^2

**at pressure of 80 kN/m^2

***derived using a Stroud Factor of 4.5

Superficial Deposits (Till)

Soil parameters	Min. Value	Max. Value	Average
Moisture content (%)	11.60	24.90	16.44
Liquid limit (%)	30	35	31.57
Plasticity limit (%)	14	16	15.29
Plasticity index (%)	15	19	16.29
Modified plasticity index (%)	11.25	15.96	12.98
Plasticity term	Low		
Volume change potential	Low		

Grading (%)	Cobble	0	0	0
	Gravel	4	20	14.43
	Sand	31	40	34.71

This stratum was encountered underlying made ground or topsoil and typically comprised firm to stiff slightly sandy gravelly clay with low cobble content. The stratum was proven to be between 1.20 and 11.20 m thick.

A summary of the in-situ and laboratory test results recorded in the stratum are presented in Table 12.

Table 12 Summary of in-situ and laboratory test results for superficial deposits

Soil parameters		Min. Value	Max. Value	Average
	Silt	22	33	27.29
	Clay	19	31	23.57
Small Shearbox	Effective Cohesion - C' (kN/m^2)	16		
	Effective angle of shear resistance - ϕ' (degrees)	34		
Compaction (2.5 kg rammer)	Optimum moisture content (%)	16.90		
	Maximum dry density (Mg/m^3)	1.69		
Triaxial	Bulk Density (Mg/m^3)	2.16	2.21	2.17
	Dry Density (Mg/m^3)	1.83	1.97	1.92
	Undrained Shear Stress (kN/m^2)*	49	149	101.2
Triaxial (remoulded – 2.5kg Rammer)	Bulk Density (Mg/m^3)	2.06		
	Dry Density (Mg/m^3)	1.73	1.76	1.75
	Undrained Shear Stress (kN/m^2)**	14	84	49
Consolidation	Bulk Density (Mg/m^3)	1.96	1.98	1.97

	Dry Density (Mg/m^3)	1.59	1.76	1.68
	Voids Ratio (Mg/m^3)	0.53	0.59	0.56
	Coefficient of compressibility (m^2/MN)	0.3	0.5	0.4
	Coefficient of consolidation (m^2/year)	4.77	10.19	7.44
Remoulded CBR (%)		0.40	0.50	0.47
SPT 'N' values		6	30	17.31
Undrained shear strength inferred from SPT 'N' values (kN/m^2)****		27	135	77.90
Undrained shear strength measured by shear vane testing (kN/m^2)		60	>120	105.87
Consistency term from field description		Soft	Stiff	-
Consistency term inferred from triaxials		Firm	Very stiff	Stiff
Notes: *note varying cell pressures between 65 and 150 kN/m^2 **note cell pressures between 20 and 24 kN/m^2 ***at pressure of 80 kN/m^2 ****derived using a Stroud Factor of 4.5				

According to the RSK report the bearing capacity of the soil for the foundation of shallow Inverter Stations can be taken as 100kN/m2, which has a significant factor of safety of 3 and those foundation should be at least 1 meter deep, fully penetrating the made ground to allow for the foundations to reach a stronger soil layer and help with mitigating any problems related to differential settlement and long-term deformations in the ground base. The approach of fully replacing any made ground with the compacted aggregate of choice will not only reduce any problems with the made ground, by fully replacing it, but will also in practice increase the design bearing capacity (something excluded from the design to allow for further conservativism) and it will allow the design to fully mitigate any differential settlement, by realizing the foundations directly on top of the stronger Glacial Till.

3. Design

The design calculation shall be in accordance with the fundamental requirements of BS EN 1990:2002, and it shall be verified that no relevant limit states are exceeded.

It shall be verified that the following limit states are not exceeded:

- Internal failure or excessive deformation of the structure in which the strength

of structural material is significant in providing resistance (STR);

- Failure or excessive deformation of the ground in which the strength of soil is

significant in providing resistance (GEO);

When considering a limit state or excessive deformation of a structural element (STR and GEO), it shall be verified that:

$$Ed \leq Rd$$

The partial factors on actions (Ed) may be applied to the action themselves or to their effects. The partial factors may be also applied either to the ground properties or resistance (Rd).

The manner in which actions with their partial factors are applied shall be determined by a Design Approach. The Design Approach 1 is used for the spread footing design, and it shall be verified that a limit state or excessive deformation will not occur with either of the following combinations of sets of partial factors.

- Combination 1: A1 + M1 + R1
- Combination 2: A2 + M2 + R1

The overall stability of the ground-structure system shall be verified also under the

Design Approach 2.

Combination A1 + M1 + R2

4. Loads on the Foundations

Applicable Loads on the Foundation can be summarized as follows:

- Dead Loads (Excluding substructure) – 55kN per support (directly taken from the SMA Specification)
- Wind Loads: $q_p = 0.70 kN/m^2$

Table 4.1 – Design Cases Summary Tabel

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Site Specific Factors
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Distance from Building to Shoreline (L_distance_shore):                          30 m
Altitude above Sea Level (A_altitude):                                          115 m
Basic Wind Velocity (V_b_map_wind_velocity):                                   24.5 m/s
Directional Factor (c_dir_factor):                                              1.0
Season Factor (c_season_factor):                                                1.0
Shape Parameter (K_shape_parameter):                                            0.2
Exponent (n_exponent):                                                          0.5
Air Density (p_air_density):                                                   1.25 kg/m^3
Probability of Annual Exceedance (p_probability_of_annual_exceedance):         0.02
Altitude Factor (c_alt_factor):                                               1.115

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Velocity and Pressure Profile
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Fundamental Wind Velocity (V_b_0):                                            27.32 m/s
Probability Factor (c_prob_factor):                                            1.00
Basic Wind Velocity (V_b):                                                    27.32 m/s
Reference Mean Velocity Pressure (q_b):                                      466.40 N/m^2
Peak Velocity Pressure (q_p):                                                699.61 N/m^2
Total Wind Force per unit area (F_total):                                    699.61 N/m^2

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- Snow Loads: $s = 1kN/m^2$

5. Calculations

Table 5.1 – Design Cases Summary Tabel

Summary table

Description	Unit	Allowable	Actual	Utilisation	Result
Sliding	kN	58.3	13.4	0.229	Pass
Base pressure	kN/m^2	551.4	115.8	0.210	Pass
Description	**Unit**	**Provided**	**Required**	**Utilisation**	**Result**
Reinforcement x-direction	mm^2	4624	1275	0.276	Pass
Reinforcement y-dir, top	mm^2	1005	340	0.339	Pass
		Allowable	Actual	Utilisation	
Description	**Unit**	**Allowable**	**Actual**	**Utilisation**	**Result**
Punching shear	N/mm^2	0.832	0.271	0.326	Pass

The full Calculation Information Produced by Tekla can be seen in Appendix B. Both a foundation design check and a pad foundation check have been conducted to further emphasize the importance of verifying all possible design cases.

6. Results

Verification of all applicable loads and possible loading combinations was achieved during the calculation process. In summary the design proposal for the Inverter Stations is deemed appropriate and suitable for the site conditions.

7. Appendix A

8. Appendix B