Appendix B. Turbine Specifications

GE Renewable Energy

Foundation Load Specification for Wind Turbine Generator Systems

3.4-140
60Hz

98m Nominal Hub Height
Standard Weather / Cold Weather Extreme
IEC Class S

GE Renewable Energy

All technical data is subject to change in line with ongoing technical development!

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1 Loads for Foundation Design

The foundation loads for the nominal hub height of 98m are given at the elevation of the bottom of the Tower, which is at a **foundation offset height h= 0.745m** above the grade elevation from which the nominal hub height of the wind turbine is defined. The loads must be extrapolated to the elevation of the foundation under design consideration. Refer to Figure 1 and Figure 2.

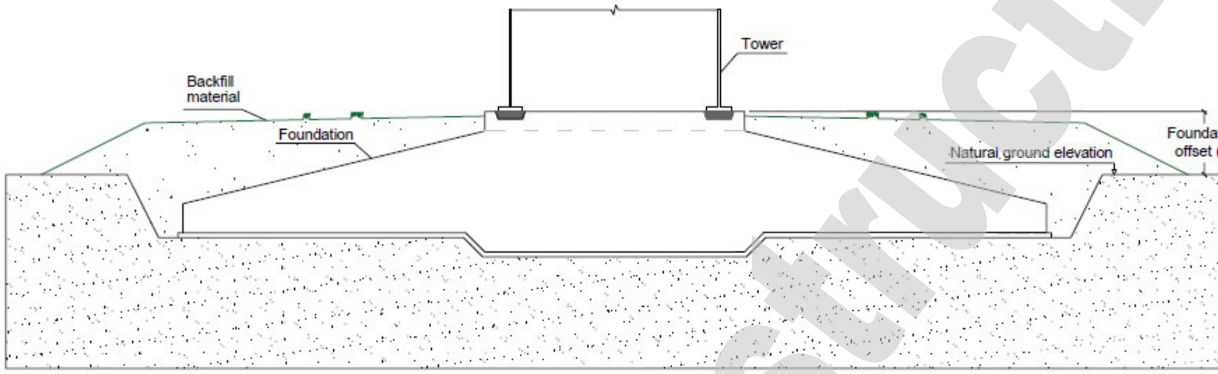

Figure 1: Foundation Offset – Tower Base to Grade

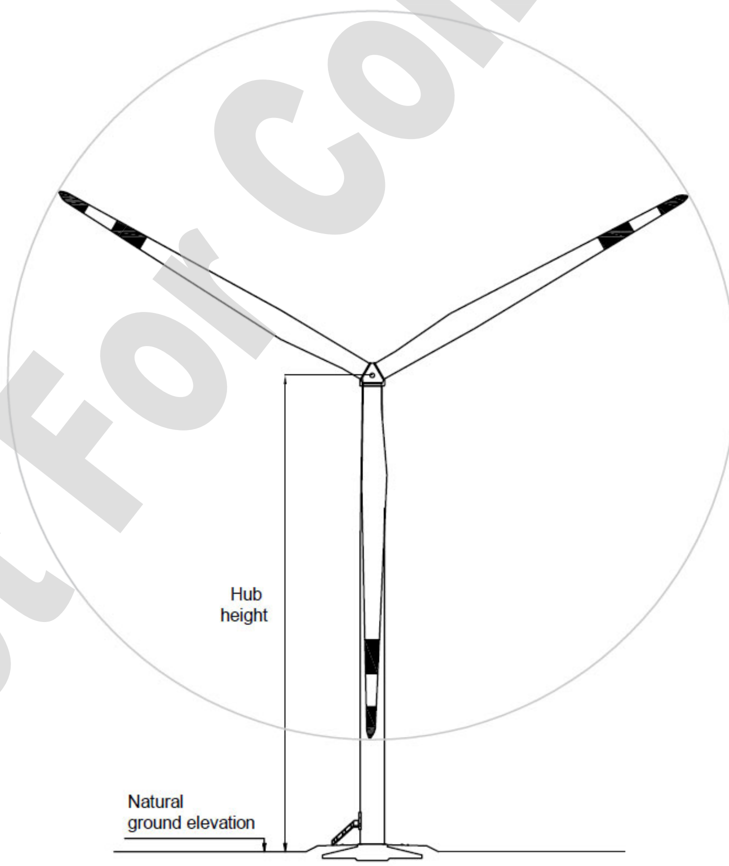

Figure 2: Turbine Elevation View

The following loads include inertia, mass and aerodynamic forces acting on the rotor and hub. They also include forces caused by accelerations or other dynamic reactions. Partial safety factors for the loads have been applied. All additional safety factors (e.g. on materials, uncertainty of calculation method, etc.) have to be applied according to the regulations. The loads in this document for the foundation design are calculated with a full dynamic simulation program called Flex 5. The loads are given in the coordinate system shown in Figure 3**.**

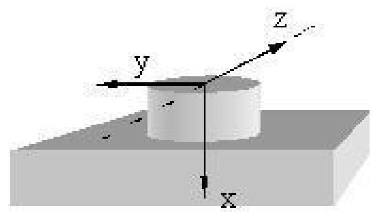

Figure 3: Coordinate System

All loads are shown with and without partial safety factors in the tables and they are directly ready for use in the foundation engineer's calculations. In addition, imperfections due to a misalignment of the tower of 8 mm/m have to be considered as per Section 3.0.

1.1 Extreme Loads

The following tables show controlling load cases (with and without partial safety factors), with all of the conditions that comprise the load case occurring simultaneously. The foundation has to be designed according to the specific country regulations. The proper final design values of partial safety factors for material properties and country specific minimum partial safety factors on loads must also be applied to these loads.

γ_F = partial safety factor for load factor design as required per International Electrotechnical Commission (IEC).

Load case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Fr [kN]	Mr [kNm]	γ [-]
DLC 7.1	**3676.5**	45.6	305.9	-4633.7	16112.2	-4313.2	309.3	16679.5	1.00
DLC 6.2	3327.8	**-951.3**	94.0	-4248.5	-6336.2	80493.6	955.9	80742.6	1.00
DLC 2.3	3370.5	58.4	**808.4**	-742.6	77368.4	-2563.7	810.5	77410.9	1.00
DLC 7.1	3431.6	-129.7	452.8	**-8973.2**	34578.8	13911.9	471.0	37272.5	1.00
DLC 2.3	3372.8	71.1	805.6	-1152.0	**77808.4**	-3037.3	808.7	77867.7	1.00
DLC 6.2	3277.1	-912.7	-89.7	-3373.3	-21052.3	**81828.4**	917.1	84493.1	1.00
DLC 6.2	3327.8	-951.3	94.0	-4248.5	-6336.2	80493.6	**955.9**	80742.6	1.00
DLC 6.2	3366.5	-892.6	-296.5	-2283.5	-43426.8	79842.9	940.6	**90888.8**	1.00

Table 1: Extreme loads – all IEC 61400 Design Situations and Load Cases; excluding partial safety factor

Load case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Fr [kN]	Mr [kNm]	γ [-]
DLC 6.1	**3548.5**	-56.0	133.9	206.1	945.7	6845.6	145.1	6910.6	1.00
DLC 6.1	3227.9	**-665.4**	198.8	-3586.8	3439.8	64834.1	694.5	64925.3	1.00
DLC 1.4	3387.3	-15.4	**672.7**	-285.9	63839.9	5749.4	672.9	64098.2	1.00
DLC 1.3	3270.5	65.8	219.7	**6604.1**	15501.7	-257.4	229.3	15503.8	1.00
DLC 1.4	3384.7	10.7	669.4	-1375.5	**65042.1**	4149.3	669.5	65174.3	1.00
DLC 6.1	3227.9	-665.4	198.8	-3586.8	3439.8	**64834.1**	694.5	64925.3	1.00
DLC 6.1	3283.0	-641.6	266.2	-2677.9	10162.6	60781.6	**694.7**	61625.3	1.00
DLC 1.4	3384.7	10.7	669.4	-1375.5	65042.1	4149.3	669.5	**65174.3**	1.00

Table 1A: Extreme loads - IEC 61400 Normal Design Situations and Load Cases Only; excluding partial safety factor

Load case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Fr [kN]	Mr [kNm]	γ [-]
DLC 8.1	**5080.4**	74.0	91.0	-748.3	2385.1	-3711.8	117.3	4412.0	1.50
DLC 6.2	3660.6	**-1046.4**	103.4	-4673.4	-6969.8	88543.0	1051.5	88816.9	1.10
DLC 1.4	4572.9	-20.8	**908.2**	-386.0	86183.8	7761.7	908.4	86532.6	1.35
DLC 7.1	3774.8	-142.7	498.1	**-9870.5**	38036.7	15303.1	518.1	40999.7	1.10
DLC 1.4	4569.4	14.5	903.7	-1856.9	**87806.8**	5601.6	903.8	87985.3	1.35
DLC 6.2	3604.8	-1003.9	-98.7	-3710.6	-23157.6	**90011.3**	1008.8	92942.5	1.10
DLC 6.2	3660.6	-1046.4	103.4	-4673.4	-6969.8	88543.0	**1051.5**	88816.9	1.10
DLC 6.2	3703.1	-981.9	-326.1	-2511.9	-47769.5	87827.2	1034.6	**99977.7**	1.10

Table 2: Extreme loads – all IEC 61400 Design Situations and Load Cases; including partial safety factor

1.2 Load Case for Check against Lift-off

To minimize the risk of soil degradation under cyclic loading, the foundation shall meet the requirements of Section 8.5.3.4 of IEC 61400-6 for the following load. This load is provided at the tower base T-flange and the check has to be done with the loads extrapolated to the foundation bottom.

Load case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Fr [kN]	Mr [kNm]	γ_F [-]
S3 Load Level	3395.9	30.3	555.0	1292.1	53257.7	7775.7	555.9	53822.3	1.00

Table 3: Load case for check against lift-off

1.3 Load Case for Check against Overturning

To ensure the stability of the foundation, the foundation is only allowed to lift-off up to its centerline for the following load cases. These loads are provided at the tower base T-flange and the check has to be done with the loads extrapolated to the foundation bottom.

Load case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Fr [kN]	Mr [kNm]	γ_F [-]
DLC 6.2	3366.5	-892.6	-296.5	-2283.5	-43426.8	79842.9	940.6	**90888.8**	1.00

Table 4: Load case for check against overturning

1.4 Load Case for Check against Sliding

To ensure the stability of the foundation, the foundation is not allowed to slide for the following load cases. These loads are provided at the tower base T- flange and the check has to be done with the loads extrapolated to the foundation bottom.

Load case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Fr [kN]	Mr [kNm]	γ_F [-]
DLC 7.1	3431.6	-129.7	452.8	**-8973.2**	34578.8	13911.9	471.0	37272.5	1.00
DLC 6.2	3327.8	-951.3	94.0	-4248.5	-6336.2	80493.6	**955.9**	80742.6	1.00

Table 5: Load case for check against sliding

1.5 Load Case for Check against Shear Failure

To ensure the stability of the foundation, the foundation has to be checked of shear failure for the soil specified in the geotechnical report. These loads are provided at the tower base T-flange and the check has to be done with the loads extrapolated to the foundation bottom.

Load case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Fr [kN]	Mr [kNm]	γ_F [-]
DLC 6.2	3703.1	-981.9	-326.1	-2511.9	-47769.5	87827.2	1034.6	**99977.7**	1.10

Table 6: Load case for check against shear failure

1.6 Load Case for Check against Pile Tension

No tension loading is allowed in the piles according to requirements of Section 8.6.4.4 of IEC 61400-6 for the following load, unless dynamic and fatigue loading is explicitly considered in the design of the piles, including all dynamic soil-pile interaction effects. These loads are provided at the tower base T-flange.

Load case	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Fr [kN]	Mr [kNm]	γ_F [-]
S3 Load Level	3395.9	30.3	555.0	1292.1	53257.7	7775.7	555.9	53822.3	1.00

Table 7: Load cases for check against pile tension loading

1.7 Load Case for Anchor Bolt Tension Check

To insure the proper setting of the anchor bolt pretension load, and to preclude loss of anchor bolt tension during operation, the following load should be considered:

Fx [kN]	Mx [kNm]	Fr [kN]	Mr [kNm]	γ_F [-]
3397.0	-2083.0	711.0	62100.0	1.00

Table 8: Load case for anchor bolt tension check

1.8 Seismic Loads

Site specific seismic loads at the base of the tower structure can be provided by GE upon request. The request should include the applicable code, and the site specific seismic parameters (e.g., design peak ground acceleration (PGA) or equivalent as per the code, soil type, etc.).

1.9 Fatigue Loads

The fatigue loads that result from the operation of the turbine are given as load spectra at the tower base T-flange and are based on 20-years of operation. The partial safety factor on loads included in the fatigue spectra is 1.0. The combined safety factors (including partial safety factors on loads and material) on these loads to be used are:

- Fatigue check of concrete according to CEB-FIB Model Code 1990:
  - $\gamma_F \cdot \gamma_{Sd} \cdot \gamma_C$ = **1.65**.
- Fatigue check of reinforcement bars acc. to CEB-FIB Model Code 1990:
  - $\gamma_F \cdot \gamma_{Sd} \cdot \gamma_C$ = **1.265**.
- Fatigue check of embedded steel parts acc. to Eurocode 3 and IEC 61400:
  - $\gamma_F \cdot \gamma_M$ = **1.265**.
- Fatigue check of embedded steel parts acc. to Eurocode 3 and DIBt-Guidelines:
  - $\gamma_F \cdot \gamma_M$ = **1.25**.

1.10Load Spectra Procedure with a Constant Mean Value

The load spectra for the Fx and Fz forces and Mx and My moments are provided in the following Excel file and are based on 20-years of operation. The unit of force is kN and the unit of moment is kNm.

Filename: Load_Spectra_3.4-140_60Hz_98mHH_EN_r02.xlsx
[Note: this Excel file is embedded / attached to this document]

Mean loads at rated wind speed (constant for all load cycles)

Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	γ_F [-]
3374.0	-6.0	478.4	-622.8	46470.0	4139.0	1.00

Table 9: Mean loads at rated wind speed (for use with the fatigue load spectra files)

1.11 Markov Matrices Procedure

The Markov Matrices for the Fx and Fz forces and Mx and My moments are provided in the following Excel file and are based on 20-years of operation. The unit of force is kN and the unit of moment is kNm.

Filename: Markov_Matrices_3.4-140_60Hz_98mHH_EN_r02.xlsx
[Note: this Excel file is embedded / attached to this document]

2 Dynamic Stiffness of the Foundation

The minimum values for the dynamic foundation stiffness that have to be achieved are:

$$k_{\varphi,min} = 5.0 \cdot 10^7 \text{ kNm/rad}; \quad k_{yz,min} = 1.0 \cdot 10^6 \text{ kN/m}$$

The minimum value for the static foundation stiffness that has to be achieved is 1/5 of the dynamic stiffness:

$$k_{\varphi,stat,min} = 1.0 \cdot 10^7 \text{ kNm/rad}$$

3 Maximum Allowed Inclination for Additional Load Consideration

Maximum allowed inclination caused by non-uniform settlement of the foundation, inaccurateness of installation, and tower axis misalignment:

- Uneven settlement due to non uniform soil properties across the foundation: 3mm/m (0.17°)
- Inaccurate installation: 3mm/m (0.17°)
- Tower axis misalignment due to solar irradiation: 2mm/m(0.11°)

To account for the impact from the total misalignment of 8 mm/m on the foundation design an additional moment of 1800 kNm has to be added at the foundation upper edge with appropriate partial safety factors.

4 Connection between Tower and Foundation

The connection between tower and foundation is established with a combination of a T-flange at the bottom of the tower, a grout joint, and an embedded anchor cage. The T-flange anchorage consists of **(144) M42 Grade 8.8 anchor bolts** that are part of the embedded anchor cage - refer to Figure 4. The foundation engineer needs to confirm the strength of the grouted joint and embedded anchor ring, and determine the pre-tension of the anchor bolts for the different design situations considering the full turbine lifespan and prestressing maintenance. Reference values are a C90 grout strength, an underlying concrete strength of C50 in the pedestal, and an anchor bolt pre-tension of 540 kN (including allowance for short and long-term tension losses). M42 refers to the final nominal outer diameter of the cold formed (mechanically rolled) anchor threads. Use of imperial anchor sizes is permissible. There shall be a minimum nominal diametrical clearance of 4mm between the tower flange hole and both the threaded and unthreaded length of the anchor bolt (for anchor bolts with mechanically rolled threads, the minimum diametrical clearance is typically dictated by the nominal outer thread diameter).

Refer to Reference [1] for recommendations and requirements on proper anchor bolt fabrication and placement, including corrosion protection, providing sufficient anchor bolt projection for engagement of the anchor bolt tensioning device and protection of anchor bolt threads during concrete and grout placement.

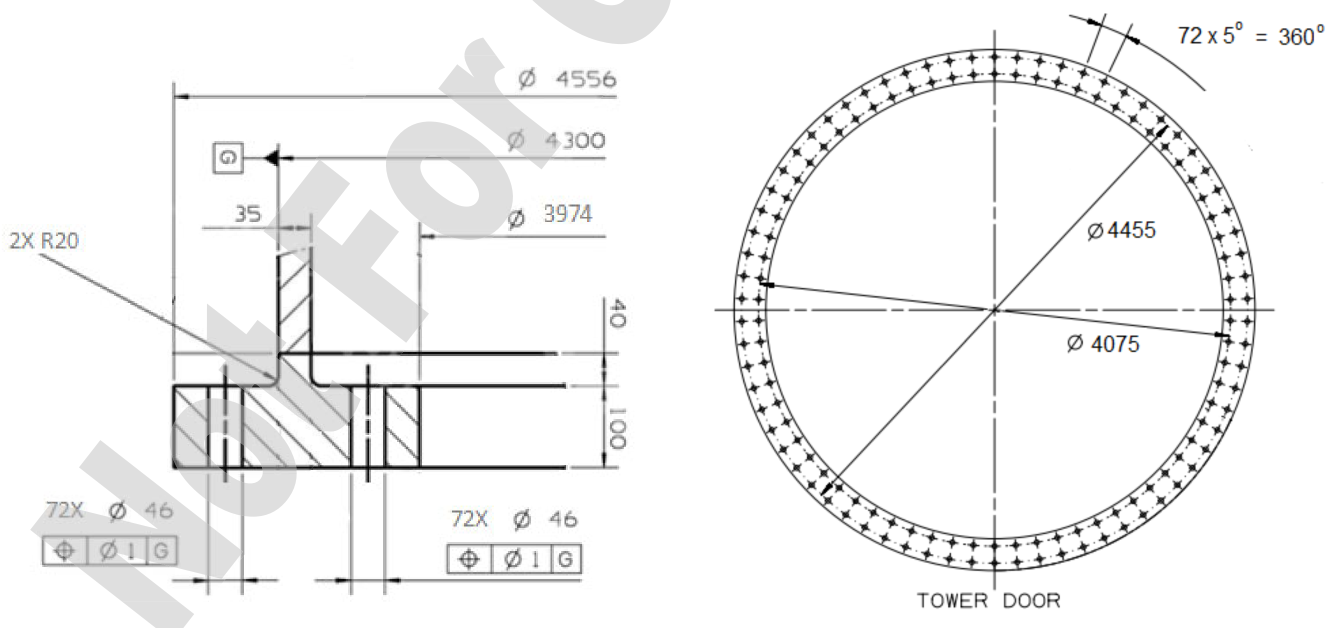

Figure 4: Tower T-Flange Geometry

5 Additional Information

Refer to Reference [1] for information on the foundation design, detailing, and execution including foundation boundary conditions, subsoil properties, spring constants for raft foundations, deep piling foundations, and short-pole foundations, a foundation design check list, etc.

6 References

[1] GE Document "*Foundation_General_Information_Tubular_Towers_Generic_xxHz_EN_rxx*", Information on the Design, Detailing and Execution of the Foundation for On-Shore Wind Turbines with Tubular Steel Tower