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List of Approved Turbine Types Coefficients

Technical Note

Presented to: MoD Defence Nuclear Organisation

12/02/2026

Document number: LATT_Coefficients_TechNote_v5 .3 Issue

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Document Summary

This technical note defines the spectral coefficients used for scalable seismic modelling of wind turbine operations within the Eskdalemuir Consultation Zone (ECZ). The coefficients are derived for a representative 12 m/s wind speed bin (11.5–12.5 m/s) and are intended for use within the Ministry of Defence (MoD) Eskdalemuir Array (EKA) Application Tool.

The coefficients apply specifically to the MoD Scalable Turbine Models (LATT-STM-A to LATT-STM-F). These scalable reference models represent turbine families from the major Wind Turbine Manufacturers (Senvion, Vestas, Enercon, Nordex, GE, and Siemens) and provide a consistent, size-scalable basis for seismic impact assessment within the MoD List of Approved Turbine Types (LATT) framework.

Each scalable turbine model is parameterised using fitted displacement spectra derived from empirical seismic measurements. The spectral components represented include operational broadband noise, blade-pass frequency components, and the first four structural bending modes. Each component is modelled using a consistent Gaussian parameterisation defined by amplitude, frequency, and shape parameters.

The coefficients defined in this technical note form the reference spectral basis used by the MoD EKA Application Tool when assessing turbine types under the LATT framework. They underpin turbine approvals supported by empirical seismic measurements within the Eskdalemuir Consultation Zone (ECZ) or (LATT-ECZ). **All coefficients presented have been reviewed and agreed with the Ministry of Defence and are approved for use within the EKA Application Tool.**

Action	Name	Date	Version	Amendment
Issue	Dr M P Buckingham	12/02/2026	V5.3	Updated Issue

Glossary of Terms

Term	Meaning
ECZ	*Eskdalemuir Consultation Zone*. The planning consultation area around the Eskdalemuir Seismic Array.
EKA	*Eskdalemuir Seismic Array*. The seismic monitoring installation operated by the MoD.
GSF	*Geological Safety Factor*. A conservative factor applied where seismic measurements are made outwith the ECZ.
Hub Height	Tower height to hub centre (m). Required in all turbine-specific identifiers.
Industry Tool	*Industry Tool* (also known as the Eskdalemuir Seismic Budget Calculator) used to assess seismic impact from wind turbines within the Eskdalemuir framework.
IRTT	*Industry-Registered Turbine Type*. A turbine type registered on the Industry Tool for visibility /decision making by development stakeholders but not yet formally MoD-approved.
IRTT-ECZ	*Industry-Registered Turbine Types* assessed using empirical measurement from within the ECZ.
IRTT-GSF	*Industry-registered Turbine Types* assessed using geological safety factors applied to empirical measurements.
LATT	MoD *List of Approved Turbine Types*. The authoritative list used within the MoD Eskdalemuir framework.
LATT-ECZ--m-MW	MoD-approved turbine type supported by empirical seismic measurements within the ECZ.
LATT-STM-A to F	MoD Scalable Turbine Models used as reference spectral models within the EKA Application Tool.
MoD Tool	MoD tool used to assess seismic impact from wind turbines within the Eskdalemuir framework.
Power	Rated electrical power of the turbine (MW). Required in all turbine-specific identifiers.
PSD	The Power spectral Density of Seismic Ground vibration (SGV)
Rotor Diameter	Rotor Diameter *is the maximum tip-to-tip distance swept by the rotating blades of a wind turbine, measured perpendicular to the rotor axis.*
STM	*Scalable Turbine Model*. A generalised, size-scalable MoD reference turbine model representing the source-term Power Spectral Density from a Wind Turbine Original Equipment Manufacturer (OEM).

Identifier rule: All turbine-specific turbine identifiers include model + rotor diameter + hub height + rated power.

Examples:
- Reference Scalable Model: LATT-STM-B
- MoD approved (measured): LATT-ECZ-SG155-155m 122.5m-6.6MW
- Industry registered: IRTT-GSF-SG155-155m 122.5m-6.6MW

1. Turbine Classification within the LATT Framework

Wind turbines assessed for seismic impact within the Eskdalemuir Consultation Zone are classified into clearly defined categories reflecting the level of empirical evidence available and the approval status within MoD and industry tools.

1.1. MoD Scalable Turbine Models (LATT-STM)

LATT-STM-A to LATT-STM-F are generalised reference turbine models to be used within the MoD EKA and Industry Tools. Each Scalable turbine model (STM) represents an OEM Wind Turbine and is parameterised using agreed spectral coefficients derived from measured data. The spectral Coefficients define the seismic source-term PSD. The STM set is size-scalable and provides a consistent and conservative reference basis for seismic assessment.

Wind Turbine Manufacturer mapping is as follows:

- STM-A – Senvion
- STM-B – Vestas
- STM-C – Enercon
- STM-D – Nordex
- STM-E – GE
- STM-F – Siemens

The spectral coefficients defined in this technical note apply to these STM reference models.

1.2. MoD Approved Turbine Types – Measured within ECZ (LATT-ECZ)

LATT-ECZ-- refers to turbine types approved by the MoD based on empirical seismic measurements obtained within the Eskdalemuir Consultation Zone. These approvals rely on measured turbine-specific behaviour and therefore reduce reliance on conservative geological safety factors.

1.3. Industry-Registered Turbine Types (IRTT)

Industry-Registered Turbine Types are turbine models registered on the Industry Tool to allow developers and project stakeholders to assess candidate machines prior to MoD approval. Registration may be supported by geological safety factors or by empirical measurements but does not constitute MoD approval. These turbine types form the pipeline for future inclusion within the LATT.

2. Background

This technical note defines the spectral coefficients to be used in the scalable modelling of seismic impact from wind turbines operating within the Eskdalemuir Consultation Zone (ECZ). The coefficients are derived for a representative wind speed bin of 12 m/s (specifically, wind speeds between 11.5 m/s and 12.5 m/s) and are intended for use within the Ministry of Defence (MoD) EKA Application Tool.

These coefficients have been agreed with the MoD and will be applied in the List of Approved Turbine Types (LATT) framework to support consistent and robust seismic impact assessment of wind farm developments.

For full details of the modelling methodology, the derivation of coefficients and seismic measurement data see the AIFCL-101-Phase4-Rev-v13 technical report. Earlier methodological foundations are provided in 140425 FMB_203_FINAL_V2 – The 2014 Report.

The scalable modelling approach relies on synthetic spectral representations of wind turbine seismic output. These synthetic spectra are constructed from measured Power Spectral Density (PSD) data across a range of turbine types, with key spectral features fitted using standardised parameterisations.

The features fitted for each turbine model include:

- Operational broadband noise (OBN)
- Blade-pass frequency (BP) components
- Structural resonances at the first four bending modes

Each component is characterised by a Gaussian distribution in the frequency domain, defined by three parameters:

- Amplitude multiplier
- Frequency
- Shape parameter (related to peak width and sharpness)

For the 12 m/s wind speed bin, with scaling to extrapolate to larger or smaller turbines, these parameters were fitted using displacement spectra from six turbine models: Vestas, Siemens, Senvion, GE, Enercon, and Nordex. The underlying measurements span multiple wind farms and deployment phases (Phase 2 and Phase 4) and were chosen to represent a broad and realistic cross-section of turbines currently or historically deployed within the ECZ.

3. Methodology

This section outlines the method used to derive the spectral coefficients for the 12 m/s wind speed bin. The synthetic displacement spectrum used for scalable modelling is described first, followed by a summary of the dataset and fitting approach used to estimate the model parameters for each turbine type. All displacement spectra used to derive the coefficients are expressed on a common reference basis corresponding to the seismic ground vibration from an equivalent single wind turbine at a distance of 1 km.

3.1. Synthetic displacement spectrum

The seismic signal from each turbine is modelled as a synthetic displacement spectrum, constructed from a combination of spectral components representing different physical sources. The spectrum is defined by the following equation:

$$SynS(f, v_w, A, f_{BP}) = OBN(f, v_w) + \Sigma_{i=1}^{4} BM_{i(f, v_w, A)} + BP(f, v_w, A, f_{BP})$$

Where:

- f is frequency (Hz)
- v_w is wind speed (m/s), here fixed at the 12 m/s bin
- A swept rotor area
- f_{BP} is the blade-pass frequency

The terms on the right-hand side represent:

- OBN: Operational Broadband Noise, A wideband spectral component capturing non-coherent seismic energy not attributable to discrete tonal sources.
- BM_1 to BM_4: First to fourth structural resonances of the tower and blades, appearing as narrow peaks.
- BP: Blade-pass frequency component dominant peak related to blade rotation, appearing at harmonics of the rotor speed

Each component is modelled using a Gaussian distribution, defined by peak amplitude, central frequency, and a shape parameter (related to peak width). Parameters were estimated by fitting these Gaussian components to measured Power Spectral Density (PSD) data, using a least-squares optimisation over the relevant frequency range. These Gaussian components were fitted to measured displacement spectra derived from turbine-specific datasets collected across multiple wind farms, summarised in Table 1 below. This method ensures that each spectral peak is accurately represented in terms of both shape and magnitude. The sum of these Gaussian components yields the synthetic spectrum used in scalable modelling.

3.2. Dataset used to fit synthetic spectra

The synthetic spectral analysis presented in this report is based on displacement PSD data collected from six wind farms, each associated with a distinct turbine model and manufacturer. These datasets were selected to provide broad coverage across turbine types currently or historically deployed within the Eskdalemuir Consultation Zone. Table 1 summarises the source and scope of the measurement data used in this analysis, including turbine type, measurement periods, and reference reports (see AIFCL-101-Phase4-Rev-v13 technical report). These datasets provide the basis for constructing synthetic spectra for the 12 m/s wind speed bin (11.5 m/s to 12.5 m/s), measured at a reference height of 80 m and normalised to an equivalent single-turbine displacement spectrum at a reference distance of 1 km, for each turbine type.

LATT- STM	Wind Farm Measured	Measurement Period		Turbine Model	Report
		Start Date	End Date		
STM-A	Middlemuir	05/05/2020	01/06/2020	3.4M114	SGV 202 Technical Report v7
STM-B	Glenkerie	16/06/2021	07/10/2021	V80	SGV 204 Appendix D.3 Glenkerie v4
STM-C	Craig Hill	10/06/2021	24/08/2021	E82	SGV 204 Appendix D.1 Craig v7
STM-D	Craig Hill	10/06/2021	24/08/2021	N80	SGV 204 Appendix D.1 Craig v7
STM-E	Langhope Rig	18/08/2021	21/10/2021	GE 1.6	SGV 204 Appendix D.5 Langhope Rig v4
STM-F	Clyde	14/07/2013	10/07/2013	SWT2.3	140425 FMB_203_FINAL_V2 - The 2014 Report

Table 1 Summary of the wind farm seismic measurement used to test scalability

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4. Coefficients for 12 m/s Wind Speed Bin

The following table presents the fitted spectral coefficients for each turbine type at the 12 m/s wind speed bin (Table 2). These coefficients define the amplitude, frequency, and shape parameters for each spectral component in the synthetic displacement spectrum, covering blade-pass frequency, four structural bending modes, and operational broadband noise. All values have been reviewed and agreed with the Ministry of Defence and are to be used directly in the MoD and Industry Tool for cumulative seismic impact assessments.

	STM-A-Senvion	STM-B-Vestas	STM-C-Enercon	STM-D-Nordex	STM-E-GE	STM-F-Siemens
Blade pass amplitude multiplier	1.10500E-25	9.33870E-25	2.45010E-26	2.62440E-25	9.89200E-25	4.16510E-25
Blade pass amplitude exponent	3.8500	4.0500	1.3500	3.2175	3.0360	3.6000
Blade pass shape parameter	0.0100	0.0220	0.0440	0.0319	0.0100	0.0400
Bending mode 1 amplitude multiplier	6.71310E-27	1.10960E-26	7.50960E-28	1.25140E-26	4.23730E-25	2.18000E-26
Frequency of bending mode 1	2.390	2.240	2.960	2.140	2.680	2.810
Bending mode 1 shape parameter	0.0820	0.0660	0.0090	0.0210	0.0100	0.0500
Bending mode 2 amplitude multiplier	3.86520E-27	4.65310E-27	7.65660E-27	5.39010E-27	9.86870E-28	1.06550E-26
Frequency of bending mode 2	3.990	4.200	4.600	4.200	4.110	3.250
Bending mode 2 shape parameter	0.0410	0.1850	0.0690	0.0700	0.0320	0.0400
Bending mode 3 amplitude multiplier	3.31510E-27	3.93720E-27	1.48310E-27	3.52650E-27	1.67270E-27	7.20380E-29
Frequency of bending mode 3	4.800	5.900	5.660	6.300	5.400	5.300
Bending mode 3 shape parameter	0.0930	0.2160	0.1200	0.1045	0.1360	0.0640
Bending mode 4 amplitude multiplier	8.53820E-27	1.07170E-29	2.27720E-27	1.04600E-27	7.89480E-27	7.50130E-28
Frequency of bending mode 4	5.800	7.100	6.890	8.000	6.700	6.200
Bending mode 4 shape parameter	0.0570	0.5000	0.0510	0.3380	0.1120	0.0980
Operational broadband noise multipliers	1.90820E-26	3.88870E-26	3.40070E-26	3.40070E-26	1.96920E-26	2.08660E-26
Tip Speed (m/s)	71.7712	69.8	60.5	69.9	77.49	77.49

Table 2 Spectral coefficients for synthetic displacement spectra at 12 m/s wind speed bin (11.5–12.5 m/s) for turbines in the LATT-STM.

5. Conclusion

This technical note defines the spectral coefficients to be used for scalable seismic modelling of wind turbines operating at 12 m/s within the Eskdalemuir Consultation Zone.

The coefficients were derived from displacement spectral data across six representative turbine types from the manufacturers Vestas, Siemens, Senvion, GE, Enercon, and Nordex, using a consistent fitting methodology. The spectral components include operational broadband noise, blade-pass frequency, and structural resonances, each parameterised for scalability.

These values have been reviewed and agreed with the Ministry of Defence and are to be used directly in both the MoD and Industry tools. Together, they provide a robust, evidence-based input to cumulative seismic impact assessments under the List of Approved Turbine Types (LATT) framework.