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Wind Farm Environmental Noise and Vibration Impact Analyses: Background Sound, Project Construction, and Assessment of Final Project Vibration Immissions

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Summary

The siting of major wind energy developments requires numerous environmental factors to be studied, not only for the finished project but for the entire life cycle of a proposed project. The final noise immissions from a wind farm project are of course important, but the noise and vibration from construction and ongoing maintenance are important to consider as well. This paper will cover the many aspects of noise and vibration that must be considered in a wind energy developer's application. A brief review of wind energy developments in the Northeast United States will be covered.

We will also discuss how the background noise level at a given site is determined among a host of factors, including hub height wind speed, precipitation, and temperature. Ground vibration measurements at varying distances from an operating wind turbine will also be presented, providing additional information on the propagation of ground vibration surrounding wind farms.

1. Recent Wind Energy Developments in the Northeast United States

The political climate has slowed the growth of land based wind farm developments in the north-eastern United States in recent years. Many of the early stage developments after the 2016 elections have been put on hold. Further delays have occurred due to the emergence of white-nose syndrome affecting bats. Any additional threats to bats are now being more carefully examined.

Offshore wind energy in the north-eastern US is poised for growth. This region offers some of the best wind resources in the world. In 2018 the state of Massachusetts awarded a contract to develop 800 MW of offshore wind. Rhode Island also started the process for development of 400 MW of offshore wind. Other coastal states such as Maine, Connecticut, New York, and New Jersey are following suite with large proposals aimed at meeting future clean energy production goals. Maritime towns and ports are vying to be hubs for construction and maintenance to this newly forming coastal industry.

2. New York State – Article 10

In the state of New York, major electric generating facilities of any type larger than 25 MW are sited according to the state's Article 10 law. This law streamlines the application process for developers, while providing a rigorous process for local input and ensuring environmental and public health laws are followed. The process begins during the early planning of a facility and continues throughout the siting review, construction, and its operation.

When this law was enacted, local communities were worried that a state board could decide matters relating to their towns. To address these concerns, and to encourage community and stakeholder participation, developers in the Article 10 process are subject to an intervenor fee equal to $1,000 for each 1 MW of generating capacity of the subject facility, but no more than $400,000. These fees can be used by the local governments and other eligible people to pay for things like expert witnesses, consultants, and certain legal expenses.

2.1 Noise and Vibration Impact Studies

Exhibit 19 of New York's Article 10 law specifies the noise and vibration impacts that need to be considered in order for an application to be approved. The following list summarizes the required studies to be conducted.

1. Measurement and evaluation of ambient pre-construction baseline noise conditions at representative potentially impacted receptors that includes:
   - Summer Daytime/Night time Ambient Sound Level (Leq, Ln)
   - Winter Daytime/Night time Ambient Sound Level (Leq, Ln)
   - Combined Summer/Winter Ambient Sound Level (Leq, Ln)
   - The ambient pre-construction baseline sound level should be filtered to exclude seasonal and intermittent noise.

2. Evaluation of future noise levels during construction and operation of the facility at potentially impacted receptors using computer modelling to include:
   - A-weighted sound levels
   - Prominent discrete (pure) tones
   - Amplitude modulated sound
   - Analysis of whether the facility will produce significant levels of low frequency noise or infrasound

3. Identification and evaluation of reasonable noise abatement measures for construction activities and in the final design and operation of the facility

4. Evaluation of the following potential community noise/vibration impacts:
   - Hearing damage (as addressed by OSHA)
   - Indoor and outdoor speech interference
   - Interference in the use of outdoor public facilities and areas
   - Community complaint potential
   - Potential for structural damage
   - Potential for interference with technological, industrial or medical activities that are sensitive to vibration or infrasound

Because these impact studies apply to all electric generating facilities, some of the required evaluations are perhaps less intended for wind farms. Nonetheless, they still need to be addressed in a developer's application for a project in the state of New York. The rest of this paper will cover a few parts of these studies that may be useful to the wind turbine noise community.

3. Measurement of Ambient Pre-construction Baseline Noise Conditions

Measurement of site ambient sound levels is already a widely studied topic, yet the rules and metrics for arriving at an agreed upon ambient level can vary. For this reason, whenever possible it is expedient to measure and record sound data such that statistical metrics can be post processed in any number of ways. This requires the saving of 1/3 octave band Leq data in at least one-second increments.

3.1 Filtering Ambient Measurements

Figure 1 presents measurement data at a proposed wind farm during a two week summertime period. The overall A-weighted sound level is plotted for every second, which totals well over 1 million data points. The daytime (7:00 am – 10:00 pm) and night time (10:00 pm – 7:00 am) periods are delineated by the blue and pink data series. Ground and met tower wind speeds are also included on a secondary axis.

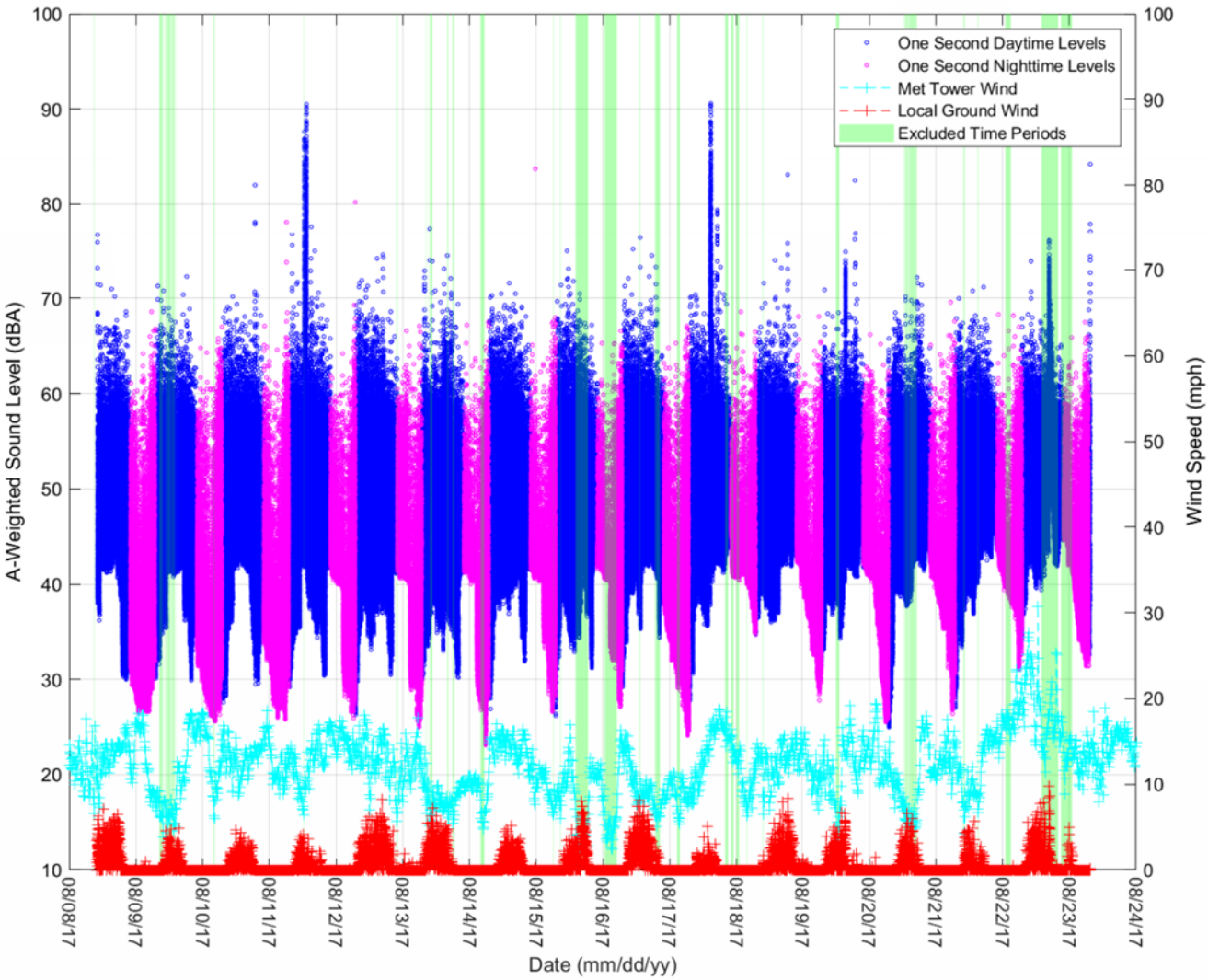

Figure 1: Representative Summer Ambient Noise Measurement Data

For this project it was required to filter days and nights for times without possible rain, snow, or temperatures outside the sound level meter specifications (-10 C to 50 C). Times when the met tower wind speed measured below the wind turbines' cut-in speed were also excluded. The shaded green areas on the chart in Figure 1 indicate the excluded time periods from the set of measured ambient data.

Figure 2 presents the ambient sound measurements at the same site during winter season. A much larger portion of the data set is excluded because of extreme low temperatures. The met tower also did not report data for some time, which required more exlusion of data.

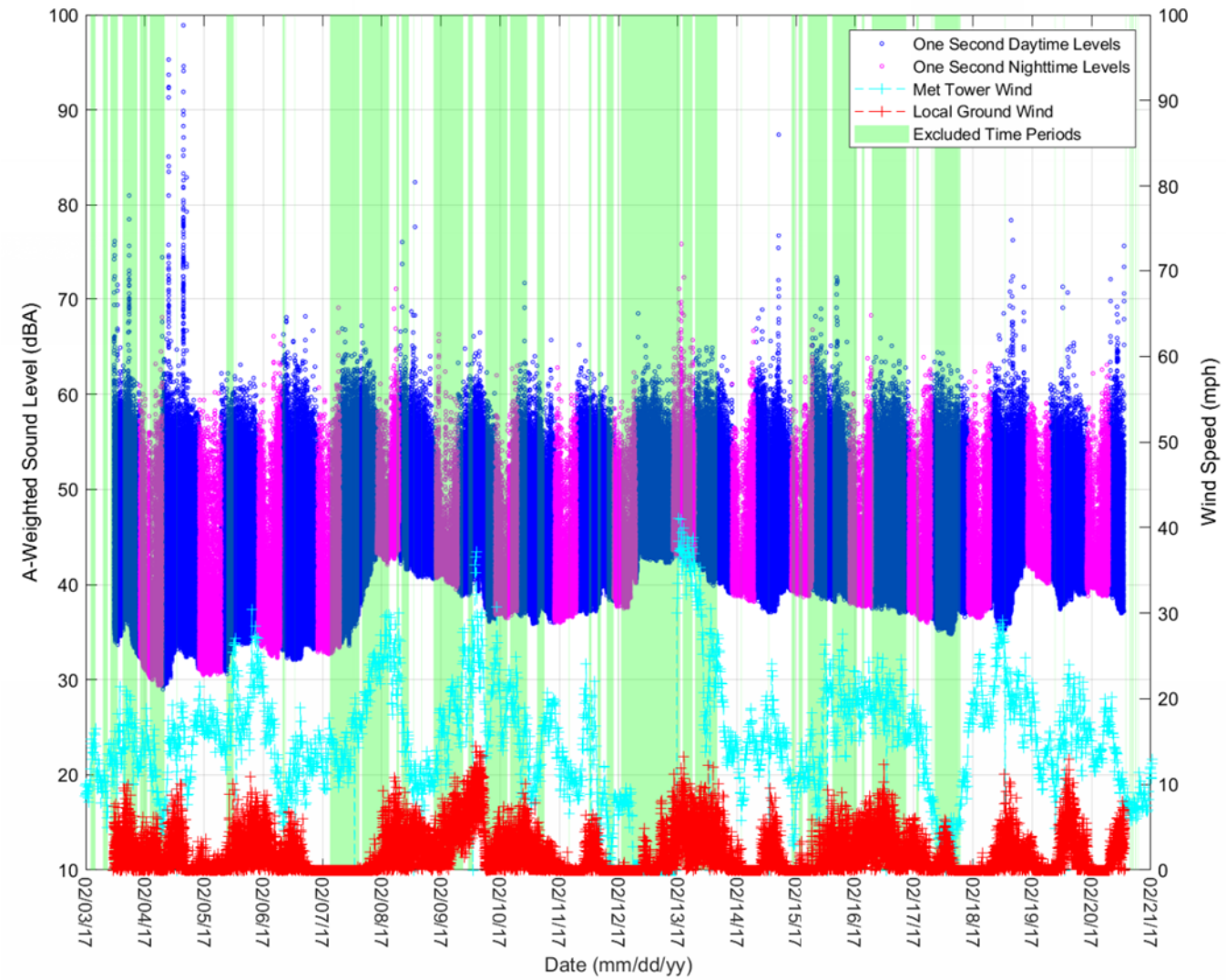

Figure 2: Representative Winter Ambient Noise Measurement Data

After filtering the summer and winter noise measurements the seasonal Leq and statistical metrics were calculated based on the remaining one-second data. Then the data from both seasons were combined in order to arrive at a year-round estimated ambient sound environment. There was roughly twice the amount of valid summer data as there was winter. Because of this the year-round statistical levels were calculated in two ways. First, the valid data points from each season were put together and the noise metrics calculated accordingly. Second, so that there was an equal number of data points for each season, the valid winter data was duplicated for the final noise metrics.

4. Construction Vibration

As discussed previously, the application for a wind development permit requires a study of the expected vibration impact that construction may have on nearby receptors. The nearest receptors could be residential or commercial buildings, each with their own limits for acceptable floor vibration. A list of equipment that might be used in the construction of a wind farm is provided in Table 1, along with the amount of ground vibration that could be expected at various distances using generic distance attenuation factors.

Table 1: Estimated Ground Vibrations Due to Various Large Construction Equipment [6]

Equipment	Distance from Activity (m)								
	10	15	30	60	90	120	150	180	215
	Estimated Ground Vibration Level (micro-m/sec)$_{rms}$								
Pile Driver (impact) (Upper range)	10,112	3,575	1,264	447	243	158	113	86	68
Pile Driver (impact) (Typical)	4,026	1,423	503	178	97	63	45	34	27
Pile Driver (sonic) (Upper range)	4,517	1,597	565	200	109	71	50	38	30
Pile Driver (sonic) (Typical)	1,135	401	142	50	27	18	13	10	8
Vibratory roller	1,273	450	159	56	31	20	14	11	9
Hoe Ram	569	201	71	25	14	9	6	5	4
Large bulldozer	569	201	71	25	14	9	6	5	4
Caisson drilling	569	201	71	25	14	9	6	5	4
Loaded trucks	507	179	63	22	12	8	6	4	3
Jackhammer	226	80	28	10	5	4	>3	>3	>3
Small bulldozer	20	7	>3	>3	>3	>3	>3	>3	>3

Figure 3 lists relative vibration sensitively limits for a number of sensitive and not-so-sensitive buidling uses. These can be used for comparing to the estimated vibration levels in Table 1.

Designation	Velocity Limits (μm/s)$_{rms}$	Applications of Limits
Potential damage to residential structures	5,000	
Offices	400	
Residences - Day	200	Average threshold of human perception / microscopes up to 40x
Residences - Night	140	
Operating Rooms	100	Perception threshold for the most sensitive persons
VC-A	50	Research labs, microscopes up to 400x
VC-B	25	Optical equipment on isolation tables
VC-C	12.6	Electron microscopes up to 30,000x / NMR, MRI, AFM
VC-D	6	Electron microscopes over 30,000x
VC-E	3	Unisolated optical research equipment
VC-F	1.56	Appropriate for extremely quiet research spaces; generally difficult to achieve in most instances, especially cleanrooms. Not recommended for use as a design criterion, only for evaluation.
VC-G	0.78	Appropriate for extremely quiet research spaces; generally difficult to achieve in most instances, especially cleanrooms. Not recommended for use as a design criterion, only for evaluation.

Figure 3: Typical Vibration Criteria [5]

Vibrations from blasting activities are not included in these charts. Blasting has the potential of producing considerable vibrations and noise. Both depend on the “charge” – the total amount of explosive set off at one time – and the “delay” (where the charge is divided into several smaller amounts and these are detonated with a brief, controlled, time delay from one to the next). At the usual distances from turbine installations to the nearest receptors the noise and vibration from blasting is unlikely to produce structural damage or cause adverse health effects. The vibration limits for residences or offices in Figure 3 may be briefly exceeded, but this is often mitigated by proper communication with potentially affected receptors well in advance of blasting activity. Blasting is usually only expected to happen a few times, whereas the other activities listed in Table 1 can happen throughout the construction process and some over the entire life of the wind turbine’s operation.

5. Ground Vibration Near an Operating Wind Turbine

Exhibit 19 of New York State’s Article 10 law requires an impact assessment to technological, industrial or medical activities that are sensitive to ground vibration. Very little reputable information could be found to support an assessment pertaining to wind turbines. Therefore, Acentech recorded vertical ground vibration measurements near operating utility scale wind turbines in a rural area. The results of one such measurement are presented in Figure 4.

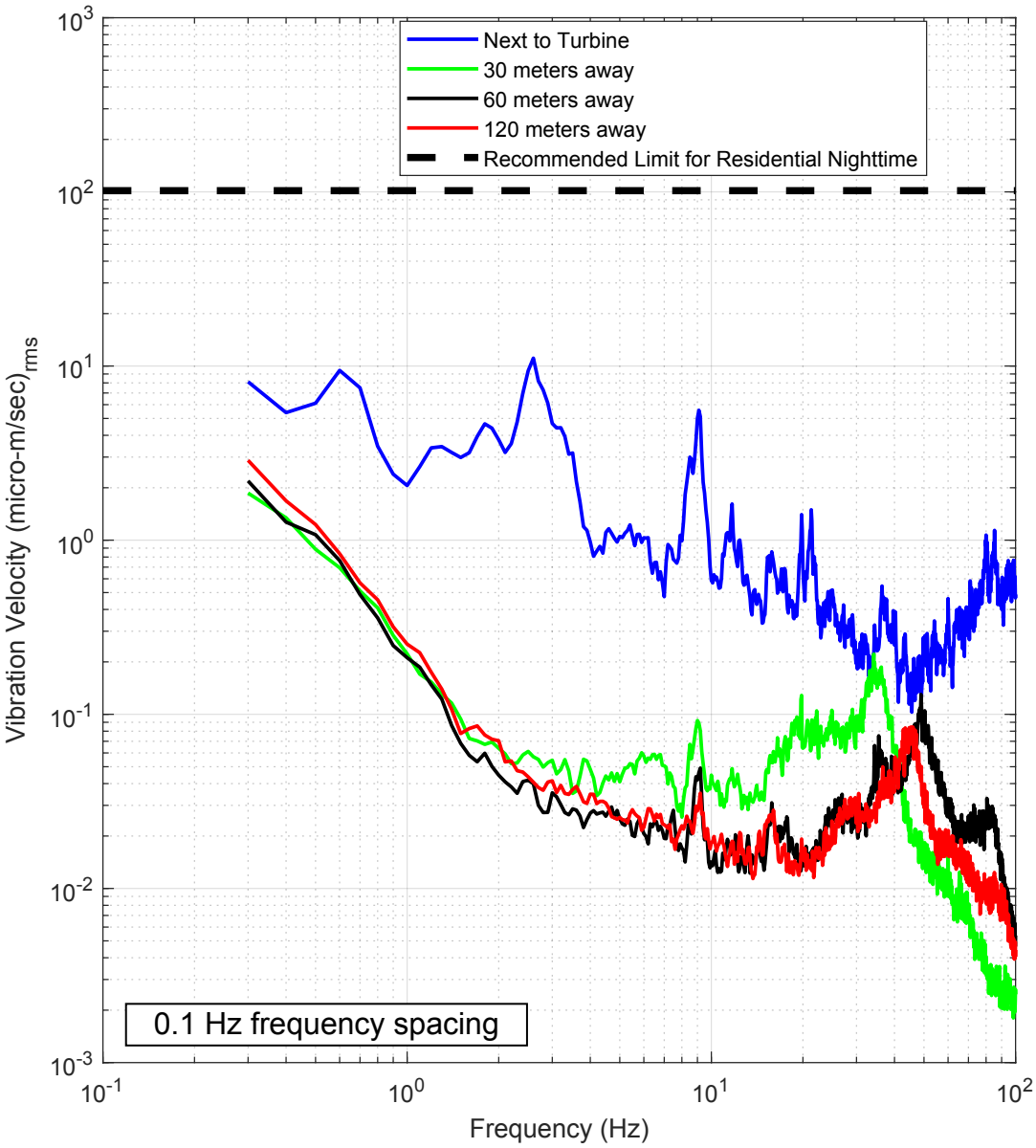

Figure 4: Narrow Band Vibration Data near an Operating a Utility Scale Wind Turbine

This chart shows the average vertical ground vibrations measured over a 10 minute period at each distance from an operating turbine. The results right next to the turbine show a peak at the blade pass frequency around 0.6 Hz as well as other harmonics and frequencies. At distances of 30, 60, and 120 meters away from the tower the vibration amplitude at the blade pass frequency is down at least an order of magnitude and perhaps even below the measurement noise floor. The dashed line on Figure 4 represents the recommended residential night time vibration limit listed in Figure 3.

For more perspective on how these measured vibrations compare to the most sensitive facilities, the data from Figure 4 has been converted to 1/3 octave band amplitudes for suitable comparison to the vibration criterion (VC) curves listed in Figure 3.

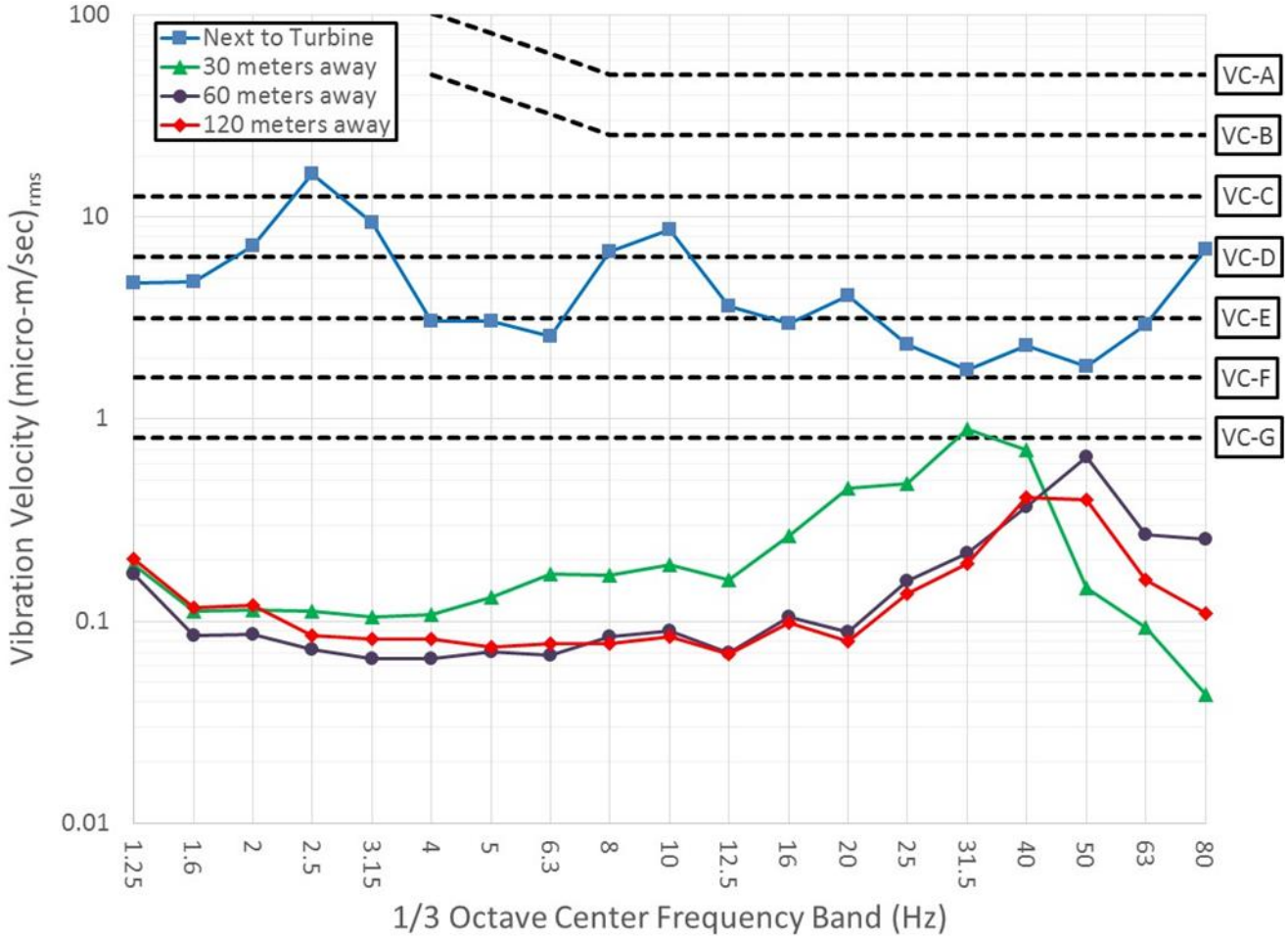

Figure 5: 1/3 Octave Band Vibration Data near an Operating Utility Scale Wind Turbine

Figure 5 indicates that even the most sensitive laboratories and hospital functions are not a risk due to ground vibrations from a wind turbine in operation.

6. Conclusions

The requirements for a wind farm development in New York State to follow the Article 10 law likely provides more work to acoustical and vibration consultants because of the wide ranging analyses that need to be considered. It is suggested that during ambient measurements the 1/3 octave and overall sound levels be recorded at least once a second so that sound metrics can be calculated (and re-calculated) based on many factors.

Guidance has been provided on the levels of ground vibration that could be expected during the construction and maintenance of wind turbines. We have also presented ground vibration

measurements near operating utility scale wind turbines. This data shows that the levels of ground vibration around a single turbine are extremely small at even short distances away from the base of the tower. It is expected that Acentech will continue to gather ground vibration data near turbines in the future to supplement this observation.

References

[1] ISO 2631-2 Evaluation of human exposure to whole-body vibration – Part 2: Continuous and shock induced vibration in buildings

[2] New York State Article 10 Regulations (http://www3.dps.ny.gov/W/PSCWeb.nsf/All/143595FA3BE36AEA852579D00068B454?OpenDocument)

[3] Pellerin, Tricia (2017) *Background Noise Variability Relative to Wind Direction, Temperature, and Other Factors* 7th International Conference on Wind Turbine Noise

[4] Sondergaard, et al. (2017) *Variation of wind induced non-turbine related noise due to position, shelter, wind direction and season* 7th International Conference on Wind Turbine Noise

[5] Ungar, Sturz, Amick (1990) *Vibration Control Design of High Technology Facilities* Sound and Vibration, July 1990

[6] United States Federal Transit Administration (2018) *Transit Noise and Vibration Impact Assessment Manual* September 2018