Research Summaries

# Industrial Ground Vibrations

## 2.3 – Industry [1]

* High speed trains: peak particle velocity 60 mm/s at 14 Hz, with total duration about 2-5 seconds (0.68 mm displacement)
* Road traffic: peak particle velocity less than 10 mm/s, with vibration 10 to 20 Hz (0.16 – 0.8 mm displacement)
  + Poorly maintained roads it increases to more than 100 mm/s, with pulse duration less than 1 second. (1.6 – 8 mm displacement)
* Pile driving: 100 mm/s to 1 m/s at frequency of 20 Hz. (0.8 mm displacement)
* Vibratory rollers: 50 mm/s at 30 Hz (0.27 mm displacement)
* Blasting: 250 mm/s 25 m away at 45 Hz (0.88 mm displacement)

## 12 – Ground Vibration Caused by Industry [2]

* Inside buildings, footfall induced floor vibration velocity is in the range from 1.1 to 3.8 mm/s between frequencies from 5 to 10 Hz.
* Transportation sources of vibration include
  + Trains
  + Road vehicles
  + Landing planes
  + Off-road vehicles
  + Fluids flow in large pipelines
  + Tunnel boring machines

## Two Case Histories of Blast- & Traffic-Induced Vibrations on the Stability of Burrows of Endangered Sensitive Ground Dwelling Animals [3]

## Potential of Vibration Studies in the Soil Characterization Around Power Plants – A Case Study [4]

* Mostly found frequencies around 8 Hz.
* Near power plants, displacement was at most 2 microns. Further away was closer to 0.8 microns, or 800 nm. This is a bit higher than wind turbines, and frequency is also higher.
* Vibration comes from the rotation of the turbine used in most types of power generation (hydro, coal, nuclear, natural gas, etc). These turbines spin much faster than wind turbines, hence the larger frequency.

Diagram, engineering drawing

Description automatically generated

# Wind Turbine Ground Vibrations

## Ground Vibration, Infrasound and Low Frequency Noise Measurements from a Modern Wind Turbine [5]

* Turbine: Siemens SWT2.3-82VS. 2.3 MW, 82.4 m rotor diameter, max hub height 100 m, min hub height 58.5 m
* Location: Wellington, New Zealand
* Used a tri-axial seismometer, but only presented vertical data in paper, as it showed the highest vibration levels
* 2 seismometers placed 92 m and 2.1 km away from turbine
* They found that ground vibration levels 50 m from a moving vehicle are of approx. similar magnitude to 90 m from the wind turbine operational at high power. -> 0.005 mm/s
* 2.1 km away, the vibrations typically do not exceed 0.0001 mm/s
* Blade frequencies between 0.30 and 0.86 Hz
* -> Need to understand the mm/s measurement for signals of vibration
* Amplitude ~5Hz at 2km away was **10-6 mm/s** -> Need to do some math to get displacement
* Amplitude ~5Hz at 90m from turbine is **10-4 mm/s -> 2 E-5 mm, or 20 nm**

## Analysis of Measured Wind Turbine Seismic Noise Generated from the Summerside Wind Farm, Prince Edward Island [6]

* Turbine: Vestas V90-3.0 MW, 80 m hub height, 44m rotor radius
* Location: Summerside, PEI, Canada
* Seismometer used: Nanometrics Trillium 120PA broadband seismometer
* Measure seismic vibration tri-axially (north-south, east-west and vertically)
* Used seismometers capable of measuring frequency in range of 0.1 – 100 Hz
* Measured at locations 125 m, 2.5 km, 4.5 km, and 10.0 km from the base of one of the turbines
* Field contains 4 turbines and location distances are relative to only 1
* Nearest station measured significant peaks throughout the higher frequencies of the frequency band of 0.1-100 Hz. This was not unexpected due to the proximity of the stations to the turbines, and other sources of seismic noise such as urban/rural roadways and the stations’ installation on local soil rather than bedrock.

Chart

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Station 125 m from turbine. HHZ is the vertical component, HH1 is the x-y component.

Chart

Description automatically generated

Station 2.5 km from turbine. HHZ is the vertical component, HH1 is the x-y component.

* **Above graphs show power spectral density**
* Sources of turbine vibration stem from similar mechanisms to that of infrasound, namely the turning of the turbine blades, with the additional complexity that any vibration of the turbine tower is transferred mechanically to the ground through the tower’s foundation. Thus not only are the various harmonics of a turbine’s blade-pass frequency observed as the compressed air pushes back on the tower, but also structural vibrations be they flexural or torsional modes of the tower, are recorded
* Identifiable structural modes at 125 m occur at 2.5 and 5.83 Hz.
* Identifiable peaks at 2.5 km are observed at 5.85, 6.49 and 7.76 Hz.
* Identifiable peaks at 5 km occur at 2.5 and 5.83 Hz.
* In the near field close to turbines, seismic noise is dominated by tower vibrational modes at frequencies >1 Hz.
* In the far field, the turbine noise is characterized by the turbine tower’s second order bending mode (2BM) at ~2.50 Hz.
* Purpose of report was to investigate safe distances between wind turbines and Earthquake monitoring stations, as turbines interfere with seismic monitoring. It was found that at low wind speeds, ~13.5 km was sufficient, but at high wind speeds, 62.9 km of separation is required.
* Amplitude -> between -100 and -120 decibels (relative to 1 (m/s)2/Hz)  
  Appears that at both 125m and 2.5 km, the amplitude for 5.85 Hz is **-110 dB (rel. 1 (m/s)2/Hz)**. -> **1\*10-11 m2/s**

Table

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Chart

Description automatically generated with low confidence

## Field monitoring of the ground vibrations adjacent to an onshore wind turbine foundation [7]

* Turbine model not disclosed. Features: 2.3 MW output, hub height of 80 m, blade rotor 93m in diameter, octagonal foundation 19 m in diameter and 2 m in thickness
* Location: Southern Ontario (Great Lakes region), Canada
* Ground vibrations are predominantly produced by vibrations related to structural resonances and blade-passing frequencies.
* Turbine field located in Great Lakes region of Southern Ontario
* Used high-frequency triaxial seismometers (Trominos) and one triaxial accelerometer.
* Trominos located at 30 m, 130 m, and 300 m from the foundation edge of the turbine.
* Accelerometer placed on base of turbine?

## Ground vibrations caused by wind power plant work as environmental pollution - case study [8]

* Turbine: Vestas V112. 3 MW, 112 m rotor diameter
* Location: Poland
* Used a single-axis piezoelectric sensor, connected using shielded cables to the four0channel VIBDAQ+ data activation module.
* Not really a great resource, honestly.

## Human perception of wind farm vibration [9]

* Turbines: Vestas V90-3.0 MW, 80 m hub height, 44m rotor radius, average rotational speed 16 rpm
* Location: Canunda wind farm, Southern Australia

## Living in habitats affected by wind turbines may result in an increase in corticosterone levels in ground dwelling animals [10]

* Turbine: Repower MM92, tower height 100m, rotor diameter 92.5m and single-turbine capacity of 2.05 MW
* Location: Poland (south-east, Rymanow)

## An assessment of non-volant terrestrial vertebrates response to wind farms—a study of small mammals [11]

* Turbine: Repower MM92, tower height 100m, rotor diameter 92.5m and single-turbine capacity of 2.05 MW
* No significant effects on non-volant small mammals in proximity to wind turbines
* Location: Poland (Southeast)

## Seismic Measurements at the Stateline Wind Project [12]

* Seismometer: Guralp CMG-40T

# References

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| [1] | M. Srbulov, "2.3 Industry," in *Practical Soil Dynamics: Case Studies in Earthquake and Geotechnical Engineering*, United Kingdom, Springer Science+Business Media, 2011, pp. 35-36. |
| [2] | M. Srbulov, "12 Ground Vibration Cause by Industry," in *Practical Soil Dynamics: Case Studies in Earthquake and Geotechnical Engineering*, United Kingdom, Springer Science+Business Media, 2011, pp. 233-257. |
| [3] | J. A. Barneich, J. Arabshshi and S. K. Duke, "Two Case Histories of Blast- & Traffic-Induced Vibrations on the Stability of Burrows of Endangered Sensitive Ground Dwelling Animals," in *Fifth International Conference on Case Histories in Geotechnical Engineering*, New York, 2004. |
| [4] | R. Sreekala, N. Lakshmanan, K. Muthumani, N. Gopalakrishnan and K. Sathishkumar, "Potential of Vibrations Studies in the Soil Characterization Around Power Plants - A Case Study," in *International Conference on Case Histories in Geotechnical Engineering*, Arlington, 2008. |
| [5] | P. Botha, "Ground Vibration, Infrasound and Low Frequency Noise Measurements from a Modern Wind Turbine," *Acta Acustica united with Acustica,* vol. 99, no. 4, pp. 537-544, 2013. |
| [6] | W. N. Edwards, "Analysis of measured wind turbine seismic noise generated from the Summerside Wind Farm, Prince Edward Island," Natural Resources Canada, Prince Edward Island, 2015. |
| [7] | P. He, J. González-Hurtado, T. Newson, H. Hong, M. Postmann and S. Molnar, "Field monitoring of the ground vibrations adjacent to an," *Canadian Geotechnical Journal,* vol. 58, no. 4, pp. 595-602, 2019. |
| [8] | S. Borowski, "Ground vibrations caused by wind power plant work as environmental pollution - case study," *MATEC Web of Conferences,* vol. 302, no. 01002, 2019. |
| [9] | D.-P. Nguyen, K. Hansen and B. Zajamsek, "Human percepion of wind farm vibration," *Journal of Low Frequency Noise, Vibration and Active Control,* vol. 39, no. 1, pp. 17-27, 2020. |
| [10] | R. Łopucki, D. Klich, A. Ścibior, D. Gołębiowska and K. Perzanowski, "Living in habitats affected by wind turbines may result in an increase in corticosterone levels in ground dwelling animals," *Ecological Indicators,* vol. 84, pp. 165-171, 2018. |
| [11] | R. Łopucki and I. Mróz, "An assessment of non-volant terrestrial vertebrates response to wind farms—a study of small mammals," *Environmental Monitoring and Assessment,* vol. 188, no. 122, 2016. |
| [12] | R. Schofield, "Seismic Measurements at the Stateline Wind project," LIGO, 2002. |
| [13] | E. A. Shumakova and M. D. Trubetskova, "Soil vibrations as a reliable recorded characteristic of," *IOP Conf. Series: Earth and Environmental Science,* vol. 321, no. 012024, 2019. |
| [14] | M. Mhanna, M. Sadek and I. Shahrour, "Numerical modeling of traffic-induced ground vibration," *Computers and Geotechnics,* vol. 39, pp. 116-123, 2012. |
| [15] | L. Auersch, "Ground vibration due to railway traffic—The calculation of the," *Journal of Sound and Vibration,* vol. 293, pp. 599-610, 2006. |
| [16] | T. G. Gutowski and C. L. Dym, "Propagation of Ground Vibration: A Review," *Journal of Sound and Vibration,* vol. 49, no. 2, pp. 179-193, 1976. |
| [17] | H. E. M. Hunt, "Stochastic Modelling of Traffic-Induced Ground Vibration," *Journal of Sound and Vibration,* vol. 144, no. 1, pp. 53-70, 1991. |
| [18] | O. Hunaidi, "Traffic Vibrations in," Institute for Research in Construction, Ottawa, 2000. |
| [19] | E. Ghasemi, M. Ataei and H. Hashemolhosseini, "Development of a fuzzy model for predicting ground vibration caused by rock blasting in surface minin," *Journal of Vibration and COntrol,* vol. 19, no. 5, pp. 755-770, 2012. |