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Wind Seismic Noise Introduced by External Infrastructure: Field Data and Transfer Mechanism

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ABSTRACT:

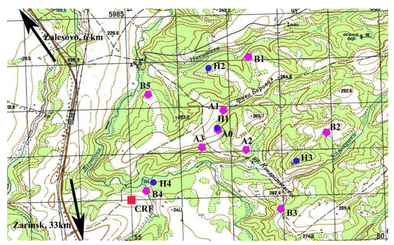
Background seismic noise generated by wind was analyzed at co-located seismic and infrasound arrays with the use of the station wind speed data. The main factors affecting the noise level were identified as (a) external structures, (b) borehole casing and (c) local lithology. The wind-induced seismic noise peaks in the spectra can be predicted by combination of inverted pendulum model for antenna towers, free- or clamped-tube resonance of the borehole casing and is dependent on the type of sedimentary upper layer. Observed resonance frequencies are in agreement with calculated modes for towers and borehole casings. Improvement of the seismic data quality can be achieved by minimizing the impact of surrounding structures close to seismic boreholes. The need and the advantage of the borehole installation may vanish and appear to be even not necessary at locations with non-consolidated sediments because the impact of surrounding structures on seismic background may significantly deteriorate the installation quality and therefore the detection capability of the array. Several IMS arrays where the radio telemetry antennas are used for data delivery to the central site may benefit from the redesign of the intrasite communication system by its substitute with the fiber-optic net as less harmful engineering solution.

1. Co-located Arrays

The data sets included seismic records and wind speed data from 5 co-located infrasound stations, namely Boshof BOSA/IS47, Tsumeb TSUM/IS35, Zalesovo ZALV/IS46, Ussuriysk, USRK/IS45 and Petropavlovsk-Kamchatskiy, PETK/IS44. The choice of the co-located arrays is explained by presence of continious meteorological data (infrasound meteorological channels for wind speed, wind direction and temperature), which exist at infrasound IMS stations only.

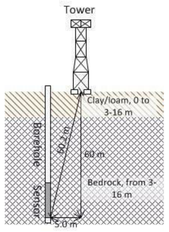
The seismic installations are uniform for 4 out of 5 arrays (borehole seismometers installed at the depth between 23 and 60 m), only TSUM station has pedestal subsurface installed seismometer. Depth of bedrock varies from 0 to 100 m, and has significant influence to the observed resonances. External structures include communication towers and masts of differen types: self-supporting towers at USRK, TSUM and PETK, guy-wired towers at ZALV and self-standing mast at BOSA.

Samples of co-located seismic/infrasound station layout:

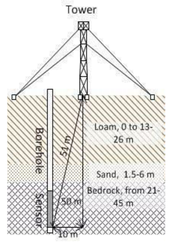


Main types of meteorological sensors used at IMS infrasound stations:

Samples of typical borehole / mast installations with lithology information:

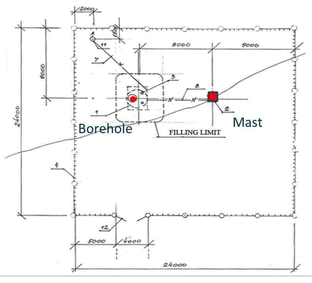


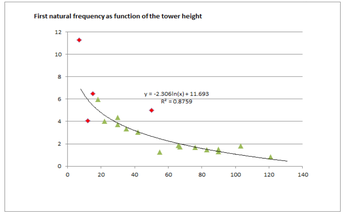
USRK, Ussuriysk



ZALV, Zalesovo

Plan of a tower and borehole location (ZALV):





Empirical dependance of the first natural frequency on lattice t towers' height. Green triangles: data from [2], [3] and [4]; Red diamonds: observed data.

2. Observed data

Observations clearly show wind-dependant peaks in the power spectra density plots at all 5 seismic stations. The analysed periods included time with wind speed from 0 to 5-7 m/s. We calculated spectral growth of the resonance signal as function of wind speed for each station, expressed in dB per m/s of the wind speed. the summary table is given below.

The observed data show clear difference between guided towers and self-supporting towers, as well as dependancy on lithology.

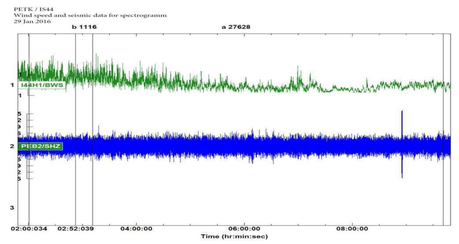
Fundamental mode peaks were often observed even during calm conditions. Other interesting observation is presense of "flora" broad peak at 2.5-3 Hz, proving the observations of Edwards et. al., 2011.

Resulting observation table:

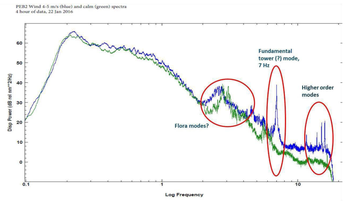
Station	Range of wind speed, m/s	Spectral growth*, dB/m/s	Type of tower	Seismometer installation
PETK	0-6	6.0	Self-supporting, 7, 15 and 28 m	Borehole, 50 m
USRK	0-5	3.3	Self-supporting, 14 m	Borehole, 60 m
BOSA	0-6	3.5	Self-supporting mast, 13 m	Borehole, 23 m
TSUM	0-8	2.0	Self-supporting, 50 and 100 m	Pedestal
ZALV	0-6	1.9	Guided, 10, 15, 20 and 25 m	Borehole, 60 m

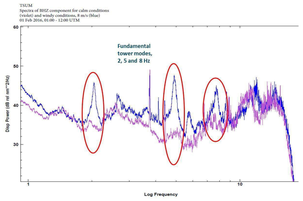
* Averaged in case of arrays

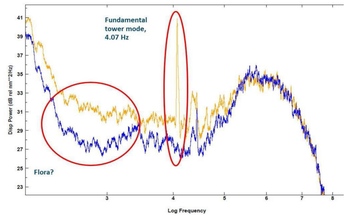
Samples of typical records in time domain, wind speed (green) and infrasonic noise (blue)

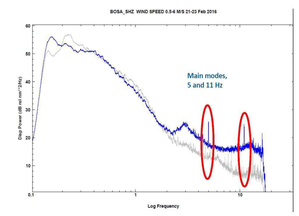


Samples of typical wind-induced resonances (frquency domain, PSD)

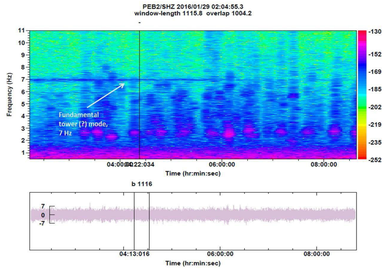








Spectrogram showing noise at 7 Hz at the PETK B2 array element



3. Data analysis

The mechanism of the observed wind-dependent resonances in our opinion includes two main contributors, inducing part and transferring part of the vibrations:

a. External structures as inducer, such as communication masts and towers, trees, solar panel structures etc., acting as inverted pendulum [1];

b. Propagation media to the sensor as transferring part, such as sediments/rocks and boreholes' casing, acting as conductor and amplifier with unique amplitude-frequency response .

The contribution of some components can be described numerically, e.g. masts and towers and borehole casings.

Transfer media (borehole cases):

The main component of the transfer media is in our opinion borehole casing tubes. These tubes act as conductors and amplifiers with given response.

The natural frequencies vibration modes of the casing pipes can be estimated from:

$$f_1 \approx 0.162 \frac{a}{l^2}\sqrt{\frac{E}{m}}, \qquad f_n \approx 2.81\left[n-\frac{1}{2}\right]^2 f_1$$

clamped bar

$$f_1 \approx 1.028 \frac{a}{l^2}\sqrt{\frac{E}{m}}, \qquad f_n \approx 0.441\left[n+\frac{1}{2}\right]^2 f_1$$

free bar

where

a – thickness of the bar/tube
m – the mass per unit length
l – tube length
E – Young's modulus for steel

Assuming borehole casing as a free- or clamped tube, two possible approximations may be considered:

a. Steel tube (casing);

b. Concrete tube (cementation),

or superposition of the above. However results are very close and differ by tenths of Hz, which is negligible for our cases. An example of calculation for a standard casing / borehole depths is:

Steel casing tube, for L~50 m, dia. 177/6 mm
Clamped: f1~0.53-0.55 Hz, f2~3.4 Hz
Free: f1~3.3-3.4 Hz, f2~8.5 Hz

Concrete cementing tube, for L~50 m, dia. 222/45 mm
Clamped: f1~0.52-0.54 Hz, f2~3.3 Hz
Free: f1~3.3 Hz, f2~8.2 Hz

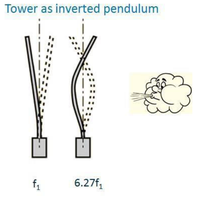
The free bar calculation meet the observation for boreholes drilled in non-consolidated sediments (e.g. majority of PETK sites, 5.3 Hz calculated, 6.5 Hz observed). However, the estimated tower natural mode is also very close to the observed resonance peak at PETK (6 Hz).

The case of the BOSA station can be taken as a good example of the calculation with known parameters, which meets the observed resonances. The two peaks at BOSA PSD plots at 5 and 11 Hz (see Fig. 8 above), can be attributed to natural modes of the borehole casing (f1=4.1 Hz) and communication mast (f1=10.2 Hz) for clamped bar, in both cases calculations are made for clamped bar.

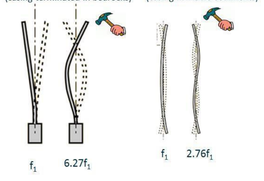
4. Discussion

- **Antenna towers affect data quality introducing noise increase and spikes in spectral domain within the working IMS passband ;**
- **It appears that the transfer function depends on the upper layer structure and less rigid layer causes more efficient transfer mechanism through the ground;**
- **Antenna towers with guy wires are a preferable solution as being a damped inverted pendulum with less efficient transfer of the wind noise;**
- **Apparently the transfer function also has the branch through excitation of tube resonances and acoustic resonances in the borehole;**
- **Arrays with radio antenna towers are potential subject for redesign with alternative intra-site communication system like f-o or private wire;**
- **Any new design of the radio intra-site communication (if selected) has to take into account these observations.**

Tower as inverted pendulum



Boreholes' case as inverted pendulum:



External structures (towers):

Dynamic response of different types of towers were described in details in [2], [3] and [4]. As stated in [2], "For most dynamic analyses under lateral loads, accurate predictions of the lowest five flexural modes suffice for self-supporting towers. Guyed towers have no normal modes of vibration as their stiffness is geometrically nonlinear." Our observations are in agreement with the statement for the cases of PETK, USRK and TSUM, where self-supporting towers are in use, in comparison with ZALV, which has guyed towers.

Calculation of the natural frequencies for self-supporting towers is quite complicated and described in details in [3] and [4]. An empirical dependency of the first natural mode ffl of standard lattice towers from their height, taken from the data given in [3] and [4] can be approximated as

ffl = -2.306ln(x) + 11.693,

where *x* is the tower height.

Calculated first flexural mode for self-supporting lattice 18-m tower is 5.95 Hz, which is in good agreement with observed resonance peak at PETK sites with 15-m towers (6.5 Hz). The 2.2 Hz peak at TSUM can be associated with 50-m towers calculated first flexural mode of 2.67 Hz.

The cases of external communication masts can be can be described by tube fundamental mode (flexural mode) model, where the the first natural frequency is:

$$f_1 = \frac{1}{2\pi}\frac{\alpha^2}{l^2}\sqrt{\frac{EJ_x}{m}}$$

where:

m – the mass per unit length (height)
Jx – flexural moment of inertia
α – coefficient depends on relation of load mass on the top of the mast mass to the mass per length, in our case can be taken as 1.87, since the load mass is negligible.
l – mast length (height),
E – Young's modulus for steel

The only station in our set with an external mast is BOSA. Calculated first fundamental mode for this case is 12.8 Hz, whilst observed on the records is 11 Hz.

References:

1. Edwards et. al. YKA Radio/Solar Tower Seismic Noise Experiment, 2011
2. Dynamic Response of Lattice Towers and Guyed Masts, edited by Murty K.S. Madugula, ISBN 0-7844-0599-9, ASCE
3. Ghodrati Amiri et. Earthquake Amplification Factors for Self-supporting 4-legged Telecommunication Towers, Al. World Applied Sciences Journal 2 (6): 635-643, 2007
4. M. Khedr. Seismic Analysis of Lattice Towers, 1998.