Wind turbines and dike safety

Influence of time dependant loads and focus on long term behavior

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Figure 1. Wind tur-
bines along Eastern
Scheldt dike, Sint
Annaland (Image
courtesy Rijkswa-
terstaat, beeldbank,
Joop van Houdt).

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WIND TURBINES AND DIKE SAFETY

INFLUENCE OF TIME DEPENDANT LOADS AND FOCUS ON LONG TERM BEHAVIOR

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multifunctional flood defenses'.*

Dikes are attractive locations to construct
wind turbines. Wind turbines can accentuate
the dike as a linear element in the landscape.
Dikes are often windy spots, that are acces-
sible for construction and maintenance using
the existing work road along the dike. With
the construction of wind turbines on a dike,
the district water board contributes to a more
sustainable world.

The authorities hesitate to permit wind
turbines on their dikes. A wind turbine on a
dike is an additional risk for the water safety
of the dike, since an accident with a wind tur-
bine during a storm may damage the dike.

But an intact, well-functioning generate
always vibrations in the soil. No structure in
a dike generates many vibrations, a wind tur-
bine generates an large number of vibrations.
Knowing that resonance and fatigue are two
important aspects in wind turbine design, the
authorities quite reasonably ask designers
to evaluate the additional risk wind turbine
pose for dike safety due to their vibrations..
Do these vibrations reduce the structural
integrity of a dike? If so, which additional risk
reduction measures can and should be taken?

General evaluation of a dike
In the Netherlands the safety of the dikes
is evaluated using comprehensive methods
based on long experience and thorough
study. However, vibrations are not included
in these methods. How can we introduce the
vibrations generated by wind turbines into
these methods?

Behavior of a wind turbine
The vibrations in the foundation of a wind
turbine have two sources: the wind makes the
blades rotate and it also excites the natu-
ral frequencies of the structure, mainly the
tower-nacelle system. At low wind speeds

(those below cut out, with the rotor turning)
both vibrations are observed. At high wind
speeds (above the cut out, when the rotor is
parked at a safe position) only the vibrations
at natural frequencies are observed.

The load at the foundation during a storm
can be considered as the summation of a
constant static part and a variable dynamic
part. These forces change with wind direction
and wind speed. Over the longer term, the
static part may also change strongly.

The forces from a wind turbine on the foun-
dation were calculated as a function of wind
speed by applying the standard design model
Fast (Jonkman & Buhl, 2005). A stiff founda-
tion was assumed. Figure 2 (page 52) shows
the results of a sample calculation. The static
component has two peak values, one just be-
low cut out speed and one at the maximum
expected wind speed. This is because, when
the wind exceeds the cut-out speed, the rotor
is parked at a position that minimizes the
wind load on the rotor. The dynamic load due
to the motion of the blades is more or less
independent of the wind speed, presumably
due to the adjustments. The dynamic load
due to the natural frequencies increases more
or less quadratically with wind speed.

Strength of the vibrations
The vibrations at the foundation and in the soil
around a 3 MW wind turbine were measured
at a moment with strong to stormy wind dur-
ing two hours. The chosen wind turbine has a
typical on-shore wind turbine design, with a
foundation made of a heavy stiff block placed
on a circular row of piles. The structure is
located in a typical soft soil area.

During the measurements, the average wind
speed was 15 m/s, with peak values up to
23 m/s, which meant the blades were rotat-

*Figure 2.
Calculated static and dynamic parts of the loading on a stiff wind turbine foundation for different wind speeds
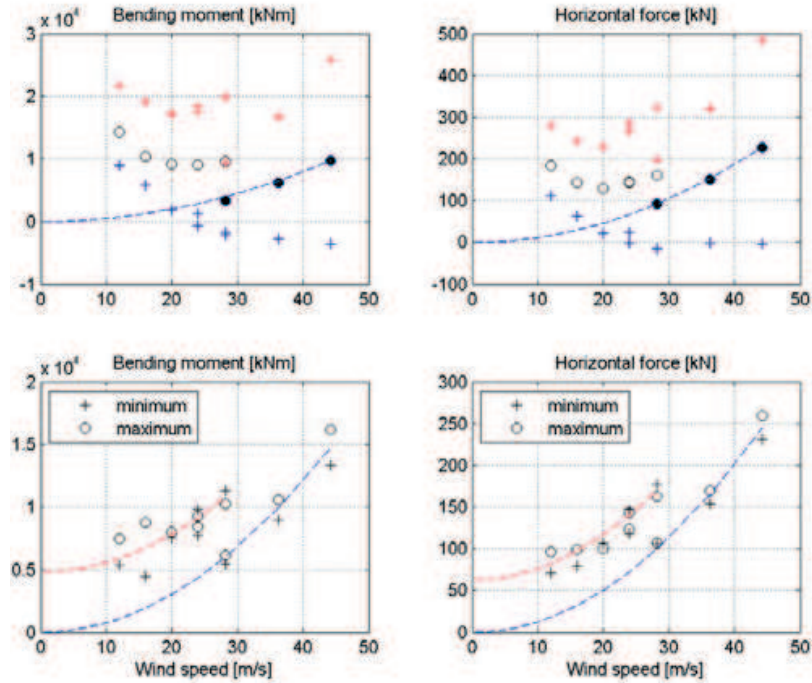(top: static part; bottom: dynamic part).*

*Figure 3.
Measured velocity in frequency domain at various distances from the wind turbine*

In the figures for small distances (9 m and 9.7 m from the wind turbine), high thin peaks are observed at the frequencies 0.3 Hz, 0.4 Hz and 0.8 Hz.

Such a peak means that the soil vibrates with that frequencies. These peaks are not observed in the points further away from the wind turbine.

The thick peak at 2.5 Hz decreases much slower with distance. This is the vibration from the resonance of the foundation. Due to its higher frequency, it has a much wider spreading around the foundation.
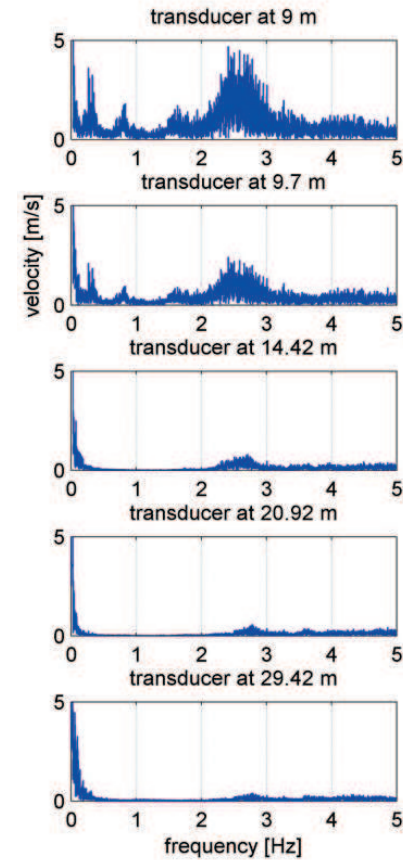
ing. The measured peak acceleration was approximately 0.02 m/s². A representation of the vibrations in the frequency domain clearly shows the behavior that is expected from numerical calculations. In addition the rotor speed, the natural frequencies of the structure are visible.

The horizontal vibrations on the foundation and in the soil were relatively high, showing a peak at a frequency that was not seen in calculations with a stiff foundation. Figure 3 shows the vertical velocity of the vibrations for several distances behind the wind turbine. At low frequency (below 1 Hz), the vibrations from the motion of the blades and tower-nacelle are visible. These are strongly damped with distance. The additional frequency peak at 2.5 Hz can be explained from the resonance behavior of the foundation under a horizontal load combined with the very low stiffness at the surface layers

Consequences for failure mechanisms
The accelerations in the soil are so low that they do not pose a direct risk to the dike's stability. Accelerations for a 3 MW wind turbine are expected to be less than 0.1 m/s² during a severe storm. Failure mechanisms that depend on acceleration of the soil include the stability of the inward and outward slopes.

The high static forces may pose a higher risk to the dike, since the tension forces which eventually result may reduce the strength of the dike material and increase the risk of piping in the area around the wind turbine.

Long-term behavior
The high number of cycles may lead to an additional risk: compaction and fatigue of granular soil. This may lead to small settlements or additional damage to the soil, that reduces the strength on the long term. It may also influence the strength just during a design storm.

The generally used models are not suitable for the number of vibrations generated by a wind turbine. therefore, an advanced model has been developed. The application of this model to the situation must still be evaluated.