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WIND TURBINES AND DIKE SAFETY

INFLUENCE OF TIME DEPENDANT LOADS AND FOCUS ON LONG TERM BEHAVIOR

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Figure 1. Wind turbines along Eastern Scheldt dike, Sint Annaland (Image courtesy Rijkswaterstaat, beeldbank, Joop van Houdt).

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 accessible 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 turbine 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 turbine 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 natural 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 foundation were calculated as a function of wind speed by applying the standard design model Fast (Jonkman & Buhl, 2005). A stiff foundation was assumed. Figure 2 (page 52) shows the results of a sample calculation. The static component has two peak values, one just below 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 during 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).

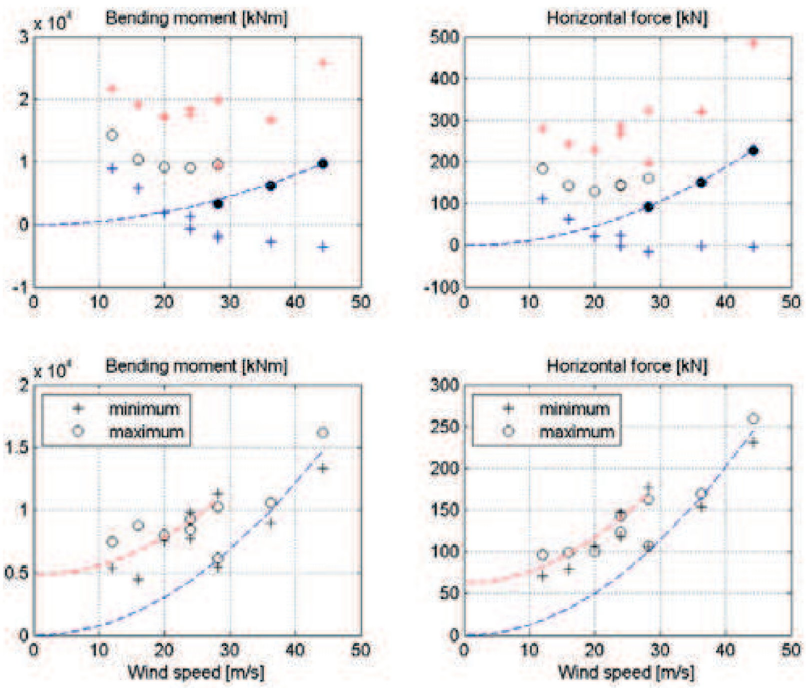
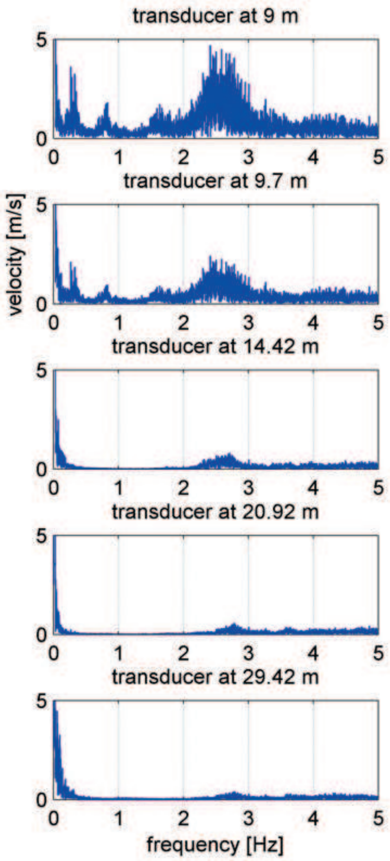


Figure 3.
Measured velocity in frequency domain at various distances from the wind turbine

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.