Note on Engineering Details

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Title: **Overall Damping for Piled Offshore Support Structures**

Ref.: GL Wind “Guideline for the Certification of Offshore Wind Turbines”, Edition 2005

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1. Introduction

The damping of offshore wind turbines significantly influences the turbine reaction and the dynamic loading. GL reviewed literature to summarize damping values to be used in load analysis of offshore wind turbines with piled support structures. Recommendation is given in Section 3 of the present note.

The overall damping of the first bending eigenfrequency of wind turbine support structures consists of the aerodynamic damping, damping due to vortex shedding and due to constructive devices and additional damping, e.g. structural damping. Compared to onshore support structures, the additional damping is influenced by further effects, e.g. soft soil and hydrodynamic damping. As a result, the additional damping for offshore support structures is higher than for onshore support structures. This additional offshore damping $D_{add,\ offsh}$ (as fraction of critical damping) consists of:

$$D_{add\,,\ offsh} = D_{radiation} + D_{vis\,,hydro} + D_{steel} + D_{soil}$$

With:	$D_{radiation}$	Damping from wave creation due to structure vibration
	$D_{vis,\ hydro}$	Viscous damping due to hydrodynamic drag
	D_{steel}	Material damping of steel
	D_{soil}	Soil damping due to inner soil friction

2. Research studied

Soil damping contributes with the biggest share of damping while it also creates the highest uncertainty as it presently results in the largest differences between theoretical solutions and measurements. The different damping contributions have been studied in [1] and [2].

Cook and Vandiver (1984) in [1] analysed an oil-platform (H = 80 m LAT) with a first bending natural frequency of 0.32 Hz in 90 m water depth on a monopile of several meters diameter. Several sea states with average values of $T_p = 7$ s und $H_s = 1.2$ m were considered.

Tarp-Johansen (2009) in [2] analysed a generic 3.6 MW turbine on a monopile of D = 4.7 m with a hub height of 80 m in 20 m water depth. The first bending natural frequency was 0.29 Hz.

The results from [1] and [2] show a very good agreement, except for $D_{radiation.}$. The resulting overall difference in total damping is solely ΔD = 0.1 %. The different damping contributions are discussed in the following.

2.1 Damping from wave creation

Radial propagation of waves from the oscillation of the structure results in highly frequency dependent damping that is proportional to the relative velocity between water and structure. $D_{radiation}$ is considered in the Morison equation by accounting for the relative velocities. For cylindrical structures with slowly changing diameters in deep water, the linear potential theory may be applied according to [1]. For a structure of several meters in diameter as well as for a minimum diameter of D = 1.2 m the result acc. to [1] then is:

$D_{radiation}$ = 0.11 %

Analysis with the 3 D Panel code WAMIT in [2] results in twice the damping of:

$D_{radiation}$ = 0.22 %

2.2 Viscous Damping

The viscous damping of the fluid results from the relative velocity of the structure. As a drag force it is proportional to the square of the relative velocity, increasing non-linearly with that. $D_{vis,\ hydro}$ is considered in the Morison by accounting for the relative velocities. The upper limit of the viscous damping for uni-directional sea states is according to [1]:

$D_{vis,\ hydro}$ = 0.15 %

2.3 Steel Damping

The material damping of steel from internal friction is, as common in the literature, stated in [1] and [2] as:

0.2 % ≤ D_{steel} ≤ 0.3 %

Additional damping of the grouted connection is not considered.

2.4 Soil damping (piled structures)

Soil damping consists of internal and geometric soil damping. Compared to all other damping contributions discussed, the internal soil damping is the most complex parameter having the highest damping contribution, as emphasized in [1] and [2]. The internal frictional soil damping depends on the material hysteresis, thus on the type of soil material. The geometric damping from wave creation of the structure in the soil (comparable to the wave creation of the structure in water) is of much less importance. In [1] a value D_{soil} of 0.53 % is experimentally determined whereas the theoretic calculation of the energy dissipation during one oscillation of the structure in the soil results in a

much higher value D_{soil} of 0.88 %.
The modal analysis of a wind turbine in [2] results, under consideration of inner soil damping of 5%, in a soil damping of the first bending mode of D_{soil} = 1 %. Further analysis in the time domain for linear- elastic soil determines a value of D_{soil} = 0.6 %. The assumption of elasto-plastic soil behaviour for high structural deflections in the soil estimates D_{soil} = 0.8 %.

2.5 Measurements on offshore turbines

The presently described theoretical investigations are reconfirmed as conservative in [2] by measured additional offshore dampings of 2 % for the offshore wind farms Horns Rev and Burbo Banks. For determination of the additional offshore damping, emergency stops with vanishing aerodynamic damping have been examined.

3 GL Recommendation for: Additional offshore damping (piled support-structures)

For determination of the applicable additional offshore damping (overall damping excluding aerodynamic damping and damping due to vortex shedding or constructive devices), two cases have to be distinguished:

a) Simulation program uses Morison equation in the formulation with relative velocities ($D_{vis,\ hydro}$ and $D_{radiation}$ implicitly considered in Morison eq.):

$D_{add,\ offsh}$ = 0.8 – 1.2 %, Best estimate 0.9 %

b) Simulation program does not account for any damping sources (mentioned under $D_{add,\ offsh}$ in 1)

$D_{add,\ offsh}$ = 1.1 – 1.5 %, Best estimate 1.2 %

Literature:
[1] M.F.Cook, J.K. Vandiver, MIT, 1982: „Measured and predicted dynamic response of a single pile platform to random wave excitation“, OTC 4285 (Offshore Technology Conference report)

[2] N.J. Tarp-Johansen, DONG Energy, 2009: „Comparing sources of damping of cross-wind motion”, EOW 2009

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