CIEM5220 Applied Dynamics – Wind & Waves

Assignment Description

The assignment concerns the dynamic analysis of an offshore wind turbine exposed to wind and wave loads. In this respect, a simplified model of an offshore wind turbine is adopted, consisting of a cantilever beam with a tip mass, see Figure 1. The tip mass represents the rotor-nacelle assembly and the cantilever beam the tower and foundation structures, respectively. Table 1 provides the parameters of the problem, for which the numerical values differ for each group. The beam is a steel thin-walled cylinder with a constant cross section.

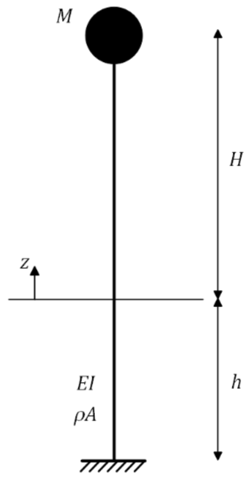

Figure 1 Simplified representation of an offshore wind turbine

Table 1 Parameters for the offshore wind turbine

Parameter	Symbol	Value
RNA mass	M	.. tonnes
Hub height	H	.. m
Water depth	h	.. m
Max. rotor speed	Ω_{max}	.. rpm
Fetch	F	.. km
Reference wind speed LC2	U_{10}	.. m/s

The turbine is exposed to simultaneous time-varying wind and wave excitations. For the analysis, it can be assumed that the turbine is non-operating (or idling), which means that the aerodynamic force on the turbine rotor can be neglected. The force on the nacelle can be neglected as well.

In this assignment, you will compare the structural response to wind and waves based on a linear and a non-linear model for two distinct load cases. More precisely, you will analyse the time-series of the moment at the mudline ($z = -h$ m), and extract relevant statistical quantities.

The assignment consists of eight steps, corresponding with the weeks of the quarter:

1. Build a parametric finite-element model of a simplified offshore wind turbine
   Construct a finite element model for a Euler-Bernoulli cantilever beam with a tip mass, consisting of a stiffness, mass and damping matrix. For the latter, a Rayleigh damping matrix should be constructed under the assumption that the first and second mode of the structure

have 2% of critical damping. Discretise the beam with 12 elements with a constant length. The model should be set up parametrically and allow for the application of lateral point forces on the nodes. Perform sanity check using analytic expressions by neglecting the top mass and compare that to the analytical value. Check tip displacement and the moment at the mudline by applying a constant distributed load over the full height.

2. Tune diameter based on required first natural frequency
   The diameter of the offshore wind turbine needs to be determined on the basis of a natural frequency analysis, so that the first natural frequency does not coincide with the rotor frequency. The target natural frequency should be at least 10% higher than the maximum so-called 1P frequency, which is determined by $\Omega_{\max}$. *The D/t ratio of the support structure should be in the range 80-120.*

3. Define representative wind and wave (co-)spectra
   Two load cases will be considered, which are summarized in Table 2. *In load case 1, the wave peak period coincides with the first natural period of the structure. The reference wind speed must be determined accordingly. In load case 2, the reference wind is given, and the wave peak period must be computed based on this value. For both load cases, the mean wind profile along the tower height can be determined, as well as the Kaimal spectra over this height and the corresponding co-spectra. Note that spectra need to be defined for each node of the finite-element model. Determine the one-dimensional JONSWAP spectra to describe the corresponding wave regimes. Give the values for the significant wave height for the two load cases.*

Table 2 Definition of the load cases

Load case	**Wave peak period**	**Reference wind speed**
LC1: Resonance response	$T_p = \frac{1}{f_1}\,\mathrm{s}$	$U_{10} = ?\,\mathrm{m/s}$
LC2: Idling in operational conditions	$T_p = ?\,\mathrm{s}$	$U_{10} = ..\,\mathrm{m/s}$

4. Generate times series for wind and waves (plus convergence analysis)
   Based on the Kaimal and JONSWAP spectra, times series of the wind and wave kinematics are determined for each node of the finite element model. To this end, random phase angle distributions can be adopted. Time series representations should be sufficiently long to capture the statistical properties of the applied wind and wave spectra. Furthermore, the sampling period should be sufficiently small to adequately capture the first and second mode of the structure.

5. Perform frequency domain analysis of linear system
   Linearise the forces acting on the structure by discarding the response of the structure in the forcing. Determine the spectra of the resulting wind and wave loads at each node of the finite element model. Using the spectra, determine the one-sided power spectral density of the moment at the mudline by performing a frequency domain analysis.

6. Perform time domain analysis of the non-linear system
   Determine the time-series of the moment at the mudline based on a time simulation of the non-linear equations, i.e. those that include relative kinematics.

7. Compare the responses from the frequency domain and time domain analyses
   Compare the time series of the moment at mudline obtained from the frequency domain analysis and from the time domain analysis in terms of relevant statistical quantities, e.g. standard deviations, extreme values, mean zero crossing periods, etc. Conclusions regarding the differences and similarities between results for the two load cases and regarding the nonlinearity of the force transfer can be drawn.

8. Assess assumptions regarding diffraction
   Given that diffraction was neglected in the response analysis of the wind turbine, this assumption must be assessed at the final stage of the assignment. Determine if diffraction could have been neglected, and argue how including it will affect the response of the structure for the two load cases. Note that you do not have to include the effect into your model and run it again, a more general consideration will suffice.