Project SRE: Part 1 - Seismic Input and Random Vibrations

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Student ID number (choose any of your group members):

A	B	C	D	E	F	G
5	3	8	1	8	2	7

INTRODUCTION

In Unit 1 of the B2 Module and during the random vibrations lectures, you have seen how we can obtain the Power Spectral Density (PSD) of a random excitation, and the PSD of the response of a structure due to the random excitation. You have also seen how this can be used to assess limit states of a structure. During the SRE lectures, we analyzed seismic motions and we have seen how the ground motions are influenced by the presence of soft soil layers. We also discussed the resonances of a multi-layered soil on top of a bedrock and the one-dimensional (1D and 2D) SH-wave propagation in a horizontally stratified soil column.

In this assignment, you have the possibility to work on these concepts and to explain the various physical phenomena associated with these effects.

LEARNING OUTCOMES

The learning outcomes of this assignment are that you will be able to:

1. Derive dynamic amplification factors for a layered soil medium based on 1D SH-wave propagation;
2. Apply the theory of random vibrations in dynamic analysis;
3. Consider additional loads together with the seismic action.

INSTRUCTIONS & QUESTIONS TO BE ANSWERED

Consider the dynamics of the offshore wind turbine (OWT) shown in Figure 1 assuming that it vibrates in the plane of the figure. The OWT is founded upon a multi-layered soil medium and excited dynamically by seismic motion at the base of that medium and sea waves along its height. You may assume that the diameters of the circular cross section are constant over its height. You are asked to analyse the multi-layered soil medium and assess the OWT response using random vibrations theory.

The list of properties of the dynamical model under consideration are as follows (note that some of the variables given are based on your (student) ID number):

- $M = 8F0 \cdot 10^3$ kg
- $J = 300 \cdot 10^6$ kg m^2
- $\rho_t = 7850$ kg/m^3
- $E_t = 210$ GPa
- $D_{out} = 9.1$ m
- $D_{inner} = 8.96$ m
- $H_t = 140 + A$ m
- $H_w = 30 + F$ m

- $H_1 = 2 + B$ m
- $H_2 = 58 + G$ m
- $H_3 = 38 + F$ m
- $G_1 = 1F0$ MPa
- $\rho_1 = 1600$ kg/m^3
- $\eta_1 = 10C0$ Ns/m^2
- $G_2 = 1D0$ MPa
- $\rho_2 = 1900$ kg/m^3
- $\eta_2 = 10E0$ Ns/m^2
- $G_3 = 1E0$ MPa
- $\rho_3 = 2000$ kg/m^3
- $\eta_3 = 10D0$ Ns/m^2

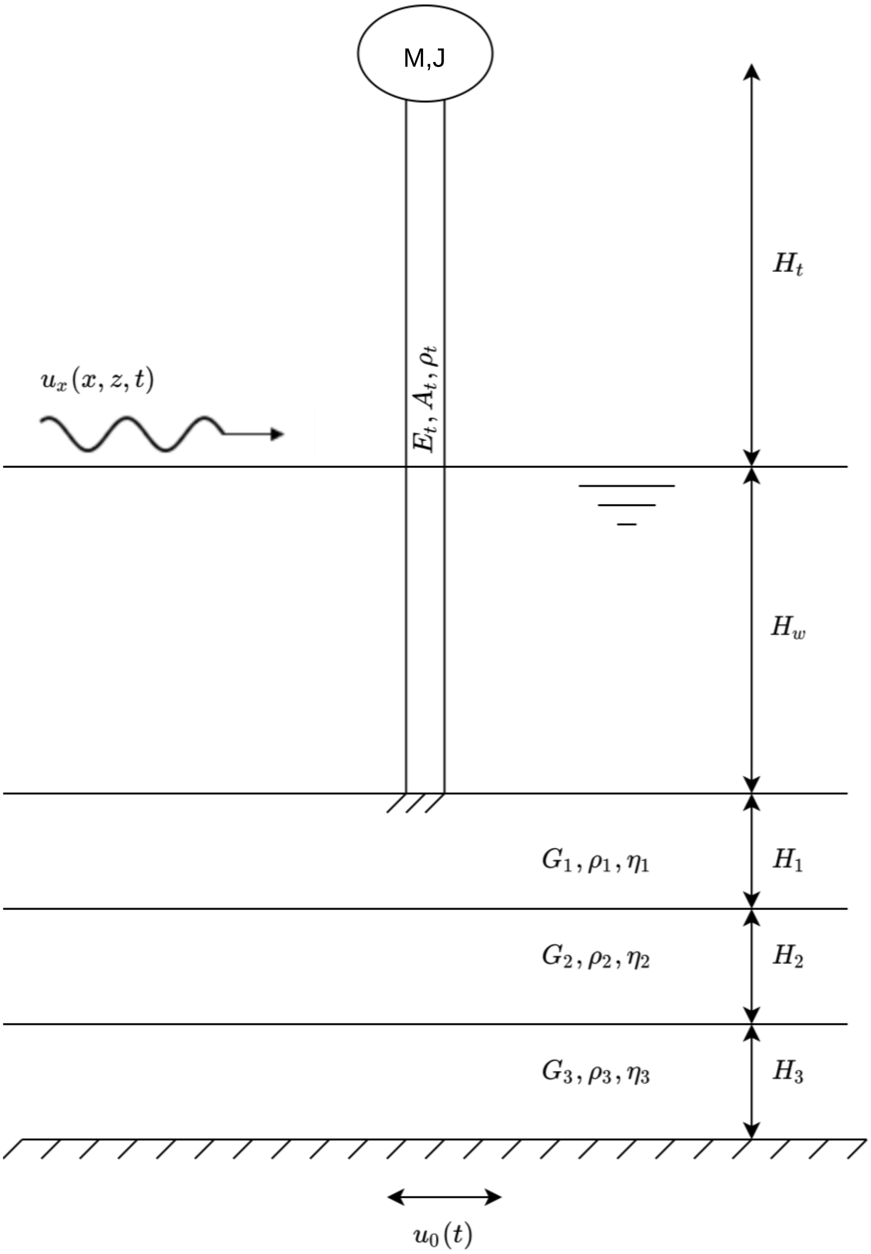

Figure 1: Simplified model of offshore wind turbine (OWT) at sea

Please answer the following questions:

1. Formulate the set of governing equations, i.e. equations of motion, boundary and interface conditions, for *the layered soil system* for a given input motion at the bedrock level assuming one-dimensional SH-wave propagation. You can ignore the presence of the OWT in your formulation.
2. Derive the natural frequencies and modes of vibration of the multi-layered soil medium of Figure 1. Plot the first 10 natural modes of vibration of the layered soil system. In your analysis, you may neglect material damping. In case you would like to include soil damping what effect will that have on the natural frequencies and the modes of vibration?
3. Derive the Frequency Response Functions $H(z,\omega)$ of the layered soil system. Plot the amplitude and the phase of the $H(z,\omega)$ at the top of layer 3 and the top of layer 1 and explain the differences you observe in the two cases. What is the physical meaning of the phase in the derived $H(z,\omega)$?
4. Formulate the set of governing equations, i.e. the equations of motion, boundary and interface conditions, of the OWT. In your formulation, please:
    - Assume that the base of the wind turbine is rigidly connected to the top of the soil, as depicted in Figure 1.
    - Neglect dynamic soil-structure interaction (SSI), i.e. assume that the motion at the surface of the ground derived by means of the analysis in question 3 is your kinematic excitation at the base of the OWT.
    - Consider the wave forces acting on the turbine by using the Morrison's equation. You may neglect the drag force.
5. Using as input the Power Spectral Densities (PSDs) of the wave forces and the seismic excitation <u>at the bedrock level</u>[1] given below, and by further assuming that the PSDs of these two dynamic loads are uncorrelated, please answer the following questions:
    - **5.1.** Compute the variance and mean value of the acceleration at the top of the OWT and of the bending moment at the base of the OWT.
    - **5.2.** Derive the probability of exceedance of 80% of the yield limit stress (S335: $\sigma_y = 355\,\mathrm{N/mm^2}$) of the OWT at the base and the probability of exceedance of the acceleration value of 0.2[g] at the top of the OWT. You may assume that the Probability Density Function (PDF) of the structural response is the normal distribution.
    - **5.3.** Please explain whether you think that the assumption of stationarity and ergodicity in the case of the seismic motions in Groningen is appropriate. To answer this question you are free to analyse the set of recorded ground motions from seismic events in Groningen discussed in class.
    - **5.4.** If one would additionally need to consider the seismic excitation in the vertical direction acting at the base of the OWT, could one assume that the horizontal and vertical PSDs of the seismic motion are uncorrelated in the case of the Groningen earthquakes? Please substantiate your answer.

[1] The PSD of the ground motion was calculated based on the assumption of wide-sense stationarity (WSS) and ergodicity.

Input PSDs of the wave force and of the seismic motion:

- For the wave force please use the JONSWAP spectrum, as explained in unit 2 (see also formula sheet for the equations). For the parameters, use the ones provided to you in the assignment of unit 2 for load case 2.

- For the seismic motion at bedrock level, please use the PSD as given in notebook: 'PSD.ipynb'. Please use the principal horizontal component as seismic input.

RESOURCES

For this assignment you are free to use the *Maple* software which can be downloaded from the TU Delft software page. The Python package *PyDynSM* can also be used especially for derivation of the FRFs of the OWT or for the SH-wave propagation in the layered system. If you do so, make sure to install the latest version.

Tips for use of PyDynSM:
- the soil can be modelled as '*Shear Beam*'.
- The beam can be modelled as '*EulerBernoulli Beam foundation attachments*'

PRODUCTS

The final product of this assignment is a report which you submit before the deadline mentioned below. The report will count for **40%** of the final grade of this part of the module.

ASSESSMENT CRITERIA

The length of the report is irrelevant for your final mark; the grade is based solely on the content of the report. The weight of each part is specified below:

Question Nr.	**Points (0-5)**	**Percentile contribution to final score (%)**	**Final score per question**
1		15	
2		15	
3		15	
4		15	
5		40	
Sum			
Grade (1-10)			

SUPERVISION AND HELP

Feedback to the assignment will be given in two specific time moments:

- **Feedback on work in progress**: Every week, a student assistant will be available to provide feedback on the progress and help you with the assignment. Please check lecture slides for the days of the consultancy sessions.
- **Feedback on the final report**: You will receive feedback when this report will be graded on Brightspace. You will have the opportunity to discuss your mark and your questions after the announcement of the grade.

SUBMISSION FORMAT

Submission deadline: June 20, 2025 at 23:59 o'clock.

Your report should be submitted electronically as a single pdf-file and the file name should be of the following form:
"CIEM5220_SRE_PW1_2025_[Your Names+Your student ID numbers]".
For example:
CIEM5220_SRE_PW1_2025_*ATsouvalas1234567_PDitmar7654321.pdf*

Please submit this assignment specification form together with your final report as a single pdf-file **(please compile all documents into a single pdf-file)** directly on Brightspace under the correspondent folder allocated for assignments. Do not forget to fill in your names and Student ID numbers at the front page of this assignment specification form. Clearly indicate the ID number used for this assignment.

The solution must be either handwritten or typed (word, LateX, etc.) and then converted to pdf-format and submitted as defined above.