Project SRE: Part 2 - Seismic Analysis of a Structure

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Student ID number:

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

INTRODUCTION

In **modules II-III** of the SRE theme, we discussed the dynamic response of SDoF and MDoF systems subjected to ground excitation. Among others, we analysed the linear and non-linear dynamic responses of these systems with various methods applied in seismic design. We also discussed the derivation of linear and non-linear response spectra, the use of theory of SDoF to treat more complex systems (*generalised SDoF systems*), and the pushover method of analysis. We introduced fluid-structure interaction for the design of liquid storage tanks and we discussed soil-structure interaction and its effect on the structural response. In this part of the project, 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 elastic and inelastic response spectra and assess their correctness.
2. Apply the pushover method of analysis.
3. Analyse the dynamic response of a complex structure subjected to seismic excitation.
4. Evaluate and compare the results of different methods of seismic analysis.
5. Consider the dynamic soil-structure interaction (SSI) of a simplified structure.

INSTRUCTIONS & QUESTIONS TO BE ANSWERED

The assignment is divided into three parts. Part A assesses the first learning outcome. Part B assesses learning outcome 2. Part C assesses learning outcomes 3-5.

Note that some of the variables are given in values based on student's ID number.

e.g. Students ID =

A	B	C	D	E	F	G
1	*2*	*3*	*4*	*5*	*6*	*7*

, $G = 1F0$MPa = 160MPa

Problem statement
You are part of a specialized team tasked with evaluating the dynamic response of a complex structural system. The structure has already undergone architectural design, and an initial structural analysis has been performed using RFEM. All applied loads must be implemented in accordance with the standards specified in EN 1990 and EN 1998.

The seismological and geotechnical features at the location, which can be used to obtain the design seismic action according to EN1998-1 (Eurocode 8), are given below:

- Geotechnical investigation: $v_{s,30} = 160\ \mathrm{m/s}$ with $N_{SPT} = 10$ (blows per 0.3m), $c_u = 50$ kPa, Poisson ratio $v = 0.33$, and average soil density $\rho = 1800\ \mathrm{kg/m^3}$.
- Seismic hazard analysis in the region:
  - peak ground acceleration of $a_{gR} = 0.33 + 0.0D\ [g]$ with $g = 9.81\ \mathrm{m/s^2}$.
  - maximum (surface) magnitude of the seismic events that are expected to contribute to the hazard is $M_s = 5.0$.
- Importance class: IV.

<u>If some information is missing, please use your engineering judgement to decide on the modelling approach/parameters.</u>

Part A: Derivation of elastic and inelastic site-specific response spectra

1) As part of the team of specialists, you are asked to use five sets of tri-axial ground motions provided and derive the motions in the three principal directions. For each tri-axial set of recordings decompose the two horizontal (as recorded) components in the principal directions and consider the vertical component acting along the third principal direction. Scale the derived horizontal ones such that the peak ground acceleration (PGA) has a value of $PGA_{hor} = a_{gR}\,\gamma_I$. Scale the vertical component according to the instructions in the Python file distributed.

You are asked to:

a) Plot the elastic acceleration response spectra of the scaled signals as defined above along each principal direction for a damping ratio of $\xi = 0.04C$ and for periods between $T = 0.00$ sec and $T = 4.00$ sec[1].
b) Derive the elastic response spectra (ERS) in the three principal directions corresponding to the mean value of the elastic spectra defined in question (1a). Explain the differences between the obtained ERS (mean value) and the ones of EN1998-1 (scaled to the same PGA).[2]

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[1] For the derivation of the elastic response spectrum, you may use the Newmark beta integration method (Python function created for this module theme which can be found in the folder: 'Python for Project Work SRE_Part 2\ERS', or any other scientifically correct method.

[2] For question 1, you are advised to use the Python file 'ERS.ipynb' located in: 'Python for Project Work SRE_Part 2\ERS\'.

2) The design team is interested in the inelastic response spectra:
   a) Derive the $R_y - \mu - T$ relationship, based on the Newmark and Hall (1982) formulation for ductility equal to $\mu = \max\{1.7D;\ 1.7F\}$. Plot the inelastic acceleration response spectra for the $R_y - \mu - T$ relationship above, using the mean ERS as computed along the two principal horizontal directions in question (1b).

   b) Derive the exact constant ductility inelastic acceleration response spectra[3], for ductility equal to $\mu = \max\{1.7D;\ 1.7F\}$, of the five signals in question (1) when decomposed along the two principal (horizontal) directions, and compute the mean inelastic acceleration response spectra. Compare these with the ones derived by using the simplified $R_y - \mu - T$ relationship of Newmark-Hall (1982). What differences do you observe and why?

Part B: Pushover method of analysis

3) To exploit the non-linearity of the structure, you have been asked to evaluate the seismic capacity by means of a pushover method of analysis. Model the structure in the FE software *RFEM* by employing a non-linear material model (you are free to define the non-linear model of your choice but please make reasonable assumptions). Please answer the following questions:

   a) State what assumptions the pushover method of analysis entails, specifically for the situation in Groningen. Are there any concerns as to the applicability of the pushover method for the induced earthquakes in Groningen?

   b) Check the displacement demand against the displacement capacity of the structure for $a_g = a_{gR}\,\gamma_I\,[g]$ using the pushover method of analysis and EN1998-1 (Eurocode 8). Choose a 'modal' lateral load pattern[4] in your analysis and justify your choice.
      - In the case that the structure does not satisfy the design requirements, specify the acceleration value a_g for which these are met. Describe shortly which measures you would consider to make the structure meet the seismic demand (no need for calculations).
      - In the case that the structure does satisfy the demand, specify for which a_g the structure would fail.

   c) In accordance with EN1998 (see footnote 4), at least both a 'uniform' and a 'modal' lateral load pattern should be applied per principal direction. Provide a reasoned argument as to whether the use of an additional load pattern is necessary (or not) in your case.

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[3] You are advised to use the Python code that has been shared for this particular question. The function can be found in the folder 'Python for Project Work SRE_Part 2\IERS'. The Matlab files shared during the classes are also applicable with some minor modifications. Alternatively, you are free to use any other software or code available.

[4] See NEN-EN1998-1:2005 en – 4.3.3.4.2.2

Part C: Seismic analysis of the structure

Please answer the following questions:

4) Perform a dynamic time history analysis with one set of input accelerations derived in question (1) along the principal directions (you are free to choose any set of triaxial motions from the list provided). Determine the maximum displacements and stresses as well as their critical locations. Explain why the chosen locations are considered critical.[5] Conclude as to the seismic capacity of the structure.

5) Perform the response spectrum method of analysis (RSA) using the design spectra provided in Eurocode (EN1998-1) and report the following results:[6]
   a) Plot the first five eigenmodes of the system together with their correspondent eigenfrequencies. Derive the modal participation mass for each of the five modes (in each direction). What do you observe as to the (potential) contribution of the different modes to the final response of the system?
   b) Determine the maximum displacements and stresses at the critical sections. Please substantiate your choice as to the modal combinations rules used for: i) the structural modes; and ii) the different directions of the seismic input motion. Are the critical cross sections the same as the ones found in question 4 above?
   c) How did you choose the upper limit of modes to be considered in the final response of the system? Are the results sensitive to this choice and why? Please substantiate your answer.
   d) Conclude as the seismic capacity of the structure.

6) In your analysis above, the effects of dynamic Soil-Structure Interaction (SSI) were neglected.
   a) Please perform a RSA assuming that the structure is not rigidly connected the ground but is supported by a (thick) rigid foundation block (feel free to define some preliminary dimensions yourself) on top of distributed elastic springs. Feel free to derive the values of the spring stiffness (in the various directions) based on any reasonable assumptions and the given soil information at site and use your solid engineering judgement. Compare the dynamic response to the one of question (5) above and assess any differences.
   b) Please perform a dynamic analysis (in the frequency domain) by considering the horizontal motion in the major principal direction and a generalised SDoF system that represents (adequately) your structure. You may assume a foundation block that is rigid at all support points of your structure (please choose the dimensions of the latter yourself as in (a) above) and that the soil is a homogeneous half-space with the properties defined earlier. Explain any differences you observe compared to the same case analysed without dynamic SSI.

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[5] Since the current version of RFEM has a bug concerning using the import from .xlsx button, you must directly copy the data from the generated .xlsx into the 'User-Defined' **acceleration** of RFEM.

[6] Since the current version of RFEM has a bug concerning using the import from .xlsx button, you must directly copy the data from the generated .xlsx into the 'User-Defined' **response spectrum** of RFEM.

RESOURCES

For answering the questions in this assignment you are free to use any software you like. However, it is (strongly) advised to use Python and RFEM software together with the provided files distributed in the assignment description folder.

PRODUCTS

The final product of this assignment is a report which you submit individually before the deadline mentioned below. Specifications on the report layout are given below. The report will count for **60%** 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 (0-10)**	**Percentile contribution to final score (%)**	**Final score per question**
1		5%	
2		5%	
3		20%	
4		20%	
5		20%	
6		30%	
Sum		**100%**	
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. You can post your questions on the discussion forum in the Brightspace page of the CIEM5220.
- **Feedback on the final report**: you will receive feedback when the report will be checked on Brightspace. You will have the opportunity to discuss your questions after the announcement of the grade.

SUBMISSION FORMAT

Submission deadline June 22, 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_PW2_2025_[Your Names+Your student ID numbers]".

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 the specific assignment. 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 you used for this assignment by filling in the blocks at the front page.
When you work out the assignment in groups and you prepare a single report at the end, please upload only ONE assignment (per group) on Brightspace. The solution must be either handwritten or typed (word, LateX, etc.), then converted to PDF-format and submitted as defined above.