Advanced Soil Mechanics: course assignment

"Useful numerical modelling in modern companies requires skilled operators who:

- *have a detailed understanding of soil mechanics and the underpinning theory for the numerical algorithms;*
- *understand strengths and limitations of constitutive models;*
- *are familiar with the software that is being used for the numerical modelling."*

(David Potts, Imperial College London)

The present assignment, and the whole course Advanced Soil Mechanics, intends to provide an answer to the "urgent call" of Prof. Potts of skilled experts in companies.

The assignment work will be performed in groups, with each member of the group receiving the same grade. The write-up will be in the form of an engineering report, consisting of a one-page letter and supporting material. Consider it a final document to be presented to your client once testing is completed. The report will be graded on the following criteria:

- Engineering content (how well the problem is solved).
- Conclusions and recommendations drawn from the analysis.
- Presentation and style in the report.

In preparing the report, the organization should be considered from the standpoint of the reader; the reader is interested in the nature of the problem, the method used to solve the problem, the results obtained from the experiments and numerical tests. There are several specific requirements and guidelines that need to be adhered to, as specified in Section 4.

The assignment is structured with four modules:

1. **Data analysis from laboratory tests**

2. **Numerical implementation**

3. **Solutions for soil improvement**

4. **Report**

Settlement of shallow foundations

A big Dutch investment group is planning to expand with a new company branch. Given the peculiar activities of the company, their special needs and high costs of existing buildings, real estate consultants have concluded that it is more convenient to realize a new office building rather than renovating an existing one.

Your firm has been contacted to assess a location, among three identified as suitable due to the vicinity of cities and important commercial infrastructures, which is preferable for the new construction.

The first location is in Italy, Piazza Grande in San Lorenzo, near Mondovì and it is characterized by clay layers, whose physical and mechanical properties can be assessed by the interpretation of laboratory tests performed by external subcontractors on soils undisturbed samples retrieved on site.

The second location is in Enschede, the Netherlands. The soil is sand and its mechanical characteristics can be extracted by lab tests to be performed by you in the Geomechanics laboratory at University of Twente.

The third location needs to be chosen **in the Netherlands**. In order to select a Dutch location and retrieve subsoil preliminary data, you can make exploit the DINO-database (Data and Information Dutch subsoil) of the Geological Service of the Netherlands. Data are freely available and easily accessible to everyone via https://www.dinoloket.nl/en.

The preliminary design of the new building has already been finalized by the team of architects and engineers of the company[1]. The design proposes a shallow concrete square foundation slab, characterised by a size (B=15m) and an embedment depth (D=5m). The maximum load expected by design is around 200 kN/m2.

[1] N.B. In the real engineering practice, the design foundation usually follows (or goes in parallel with) the choice of the location and the soil characterization, as the soil characteristic determine the type of foundation selected and the design. In this assignment, for the sake of simplicity, we assume decisions about the foundations have been already made. This can be the case if, for example, specific design constrains exist, related with the design of the underground floors of the building.

1.1 Analysis of data from external laboratory tests

Goal of this module is to extract mechanical properties for the soil of the first location. Data from laboratory tests are provided to characterize the mechanical properties of the soil in the first location indicated for possible construction. Tests are performed on natural clay sampled during site investigations at different depths. The set of tests includes:

- 3x Consolidated Isotropic Drained (CID) triaxial tests on samples at different depths
- 3x Consolidated Isotropic Undrained (CIU) triaxial tests on samples at different depths

As usual in engineering practice, tests have been performed from subcontractors. Only in a second stage your firm has been involved in the project for analysis and final assessment. You have to utilize the material provided to you for your own goals and not all the data are necessarily useful for your assessment. It is part of the challenge to recognize, organize and use the data at your convenience.

Minimal items to extract from the data to be used further in your model (Section2) are:

- CSSM parameters) and initial state coefficients.
- Total and fffective young modulus (*E, E'*) or Shear stiffness (*G*) for each test, tangent and secant in the stress range relevant for your application.
- Whatever you consider relevant to justify your choices…

Minimal items to plot in the report are:

- Deviatoric stress *vs*. deviatoric strain plots for the different tests.
- Volumetric strain *vs*. deviatoric strain plots for the different tests.
- Pore pressure *vs*. deviatoric strain plots for the different tests.
- Plots of the volumetric and stress paths (CSSM plots), combining the consolidation and shear stages.

Remember that we are investigating clays, short-term and long-term behaviour might be very different. The focus is on the long-term (long life of the structure). However, you might want to pay attention to the short-term as well.

1.2 Analysis of data from tests performed at University of Twente

The goal of this module is to determine the mechanical properties of the soil in Enschede. You will conduct Direct Shear tests on Enschede sand in the Civil Engineering laboratory at the University of Twente. Detailed instructions on the procedure are provided in a dedicated paper available on Canvas. It is advised to conduct at least three tests, selecting the range of normal stresses based on the expected loads in your design. To support your assignment, we will compile data from all tests and make them available to all groups.

Minimal items to extract from the data to be used further in your model (Section2) are:

- Shear stiffness (G) for each test, tangent and secant in the stress range relevant for your application.
- Shear strength parameters, ϕ' and c'.
- Whatever you consider relevant to justify your choices…

Minimal items to extract and plot in the report are:

- Shear stress *vs*. shear strain plots for all tests.
- Vertical strain vs shear strain and void ratio with shear strain for all tests.
- The failure envelope, i.e., the shear stress at critical state (and/or peak) vs normal stress for all the tests.

1.3 Data analysis from CPT tests

Choose a possible location in the Netherlands for which data of Cone Penetration Tests (CPT) and groundwater level depth are provided, using data available https://www.dinoloket.nl/en/subsurface-data.

Identify the stratigraphy and the mechanical properties of each layer from the available data. Make some reasonable assumptions on the properties not available.

Minimal items to extract from the data and include in the report are:

- Schematization of the soil stratigraphy and position of the water table.
- Friction angle of each of the layers identified.
- Young modulus (E) or Shear stiffness (G) of each of the layers identified.
- Whatever you consider relevant to justify your choices…

Minimal items to extract and plot in the report are:

- Profile of cone resistance and friction angle and stiffness parameter with depth, indicating the water table depth.
- Soil stratigraphy reconstructed by interpretation of the cone penetration tests.

Propose a geotechnical investigation campaign to evaluate the not available soil properties that you assumed in this preliminary phase. In a second stage, you will need to postprocess the data, perform model calibration, and extract the mechanical parameters relevant for your numerical implementation. The calibration procedure must be appropriate, careful, and illustrated in detail.

2. Numerical implementation

Goal of this of this module is to transfer the physical and mechanical information inferred from the data analysis performed in Section 1 in a continuum model and use a finite element software to model the shallow foundation problem.

- Choose a finite element software that you know/like. If you don't have any preference, we suggest using COMSOL as introduced in the course.
- Set up in the FEM framework the shallow foundation settlement problem. Mesh dimensions should be chosen such that the boundaries do not affect the solution. A mesh extended at least 3xB radially and to a depth of 3xB is recommended. If the mesh results too expensive computationally or hits the nodes-limit allowed from your software, mesh size can be enlarged, especially far from the foundation.
- Assume the Mohr-Coulomb or CamClay model, based on the soil and the type pf data available.
- Assume for the soil an isotropic, linear elastic behaviour in the regime before yielding.
- Implement the soil parameters that you extracted from the data, lab experiments data and in situ test data for the three locations.
- Reproduce the initial conditions; apply the load; calculate the settlement.
- You can visualize the footing behaviour by plotting the vertical load *vs* vertical displacement.
- Measure any other interesting quantities/fields, e.g., stress or strain fields in the vicinity of the foundation.
- Compare the values of settlement that you obtained for the three soils and assess which location is preferable to proceed with the contractor project.

3. Proposal for soil improvement

Assume that your client has, for some reason, a preference for the site that shows “worst” properties. You are asked to propose a technical solution for soil improvement, aiming to enhance the mechanical properties of the soil to match or surpass those identified as preferable in Section 1 of the analysis.

Assignment groups characterized by an **ODD number** should choose a solution from group B of the classification by ISSMGE TC[2] on Ground Improvement techniques; assignment groups characterized by an **EVEN number** can select a technique from groups C or D in the same classification.

The technique proposed must be rooted in the literature and properly elaborated in the report. You are asked to elaborate your choice in the CSSM framework, as follows:

- Explain which one(s) among the Critical State parameters will be affected by the ground improvement treatment.
- Implement the solution in the FEM model you have created, by modifying the CSSM parameter(s).
- Back calculate the extent of your intervention, i.e., “how much” the reference parameter(s) must change to achieve the desired soil performances.
- Use the information gathered at the previous points and try to elaborate on the actual cost/feasibility of your proposal.

The improvement solution should be effective, feasible and (economically) sustainable. In real life, your proposal would be accompanied by a technical-economic feasibility check as well as cost-benefits analysis.

[2] You can find the report in Canvas/Syllabus/Lesson10, or in the Module page of Lesson 10.

4. Report

Write a report about your results in the form of an engineering report to a client. There are several specific requirements and guidelines that need to be adhered to.

Title Page

The title page should include the name of the assignment, the reference to the course (Advanced Soil Mechanics 2023), the name of your firm and the group members.

Engineering Cover Letter

The engineering cover letter is a brief summary of the tests that were performed, the results that were found, and any recommendations that you make.

The outline of the cover letter should be as follows:

- List the client's name, address, etc. on the top left of the page.
- If the client has a title, for example Andrew Drescher, PhD, then always greet the client with "Dear Dr. or Prof. Drescher." Avoid using informal greetings.
- The first paragraph is used to remind the client of when he/she contacted you and what the contact was for.
- The second paragraph is used to briefly describe the available data and the procedures used for the analysis (data, software, model, etc).
- The third paragraph is used to state the test results that you found.
- The fourth paragraph is used to state your final recommendations that you want to make within the context of the project.
- The last paragraph is used for closing salutations and thanking the client for sending his/her business your way.
- Close the letter with "Sincerely" and supply your ***name, address, and phone number***.

Table of Contents

The table of contents should follow the cover letter. It should include report section titles, figures, and appendices with their corresponding page numbers.

Procedure

Type up the procedure used to perform the data analysis, calibration, and numerical implementation. Your goal is to provide a resource by which someone who is generally familiar with the subject could EXACTLY reproduce your work. You must cite material taken from your manual or any other sources. You don't need to type portions of the procedure exactly as listed in the manual or some other published source. Instead, you may simply state the resource that contains the procedure you followed. This is also an appropriate place for a description of the soils you analysed.

Results

Results consist of graphs, figures, and/or tables that present your findings in a concise manner. Additionally, this section should have text that describes what you are presenting in each of your graphs, figures, and/or tables.

Your results should be either neatly drawn or computer generated. In general, if the x and y axes have the same units (e.g., Shear stress in kPa versus Normal stress in kPa), then the scales of these axes should be equal.

All graphs, figures, and tables should be clearly presented such that they could be removed from the report and still maintain their meaning. Thus, all graphs, figures, and tables should have a title, brief soil description, type of test, date on which the test was performed, and the names of the persons who performed the test.

A table summarizing the results at the beginning (first after the table of content) or at the end of the document is very commonly used and highly appreciated by the client.

Sample Calculations

Sample calculations are intended to show exactly what calculations you performed to obtain your results. They include numeric examples. If a calculation is repeated many times in a spreadsheet, show a sample calculation for only one of the data points. It is important to include these in the body of your report (NOT in an appendix). These can be written up as a separate section or they can be included with the results.

Recommendations

List any recommendations that you have in this section. These may refer to your trials with improving techniques.

References

Any materials that you reference need to be cited. This is not as much of a technical issue as it is a professional ethics issue. ***This is very important***. You may use any sensible format for your references; just be consistent and use the same format throughout your report.

Appendices

If you have extensive data or a long calculation that may be of interest to someone reading the report but is not necessarily crucial to the message you are conveying in the report (multiple graphs), then an appendix is appropriate. For your reports, your data and spreadsheet calculations should go in an appendix. Include only the first page of long spreadsheets.

Things to make your task easier:

- Write the body of the paper first. Don't try to write the cover letter first. When you see the data and results, it becomes a much simpler task to make recommendations to the client.
- Keep the cover letter brief. Graphical and tabled results are not part of the cover letter, but it is necessary to tell the client where to find them. Single sentence and numerical results such as, *"friction angle and effective cohesion of Soil_1 are*

ϕ=22° and c=300kPa" or *"the expected long-term settlement of the foundation in the Dutch location is…"* should be included in the cover letter.

- Recommendations are reiterated in the cover letter, always.
- Double check to make sure that your units are consistent and accurate; the same units must be used in the tables, graphs, and cover letter.
- Avoid using first person narratives. It is not appropriate to write out a cover letter using '*I'* and *'we'*. First person is of very limited use in the geotechnical engineering community.