Project-based learning on the design of retaining walls for geotechnical and civil engineering students

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ABSTRACT: This communication details a teaching method of the retaining wall design for future geotechnical and civil engineers, through the implementation of a project-based learning. The case of an inverted T-shaped (or cantilever) reinforced concrete wall is chosen, as it integrates two disciplines that were previously taught separately: geotechnical engineering and structural mechanics. This also enables the students to grasp the multidisciplinary features of a real situation. The project involves the design of a wall to satisfy external and internal wall stabilities following the Eurocodes (7 and 2), without resorting to dedicated software, with a view to assimilating the concepts. Additionally, a small-scale model is considered during the project, that highlights the different modes of wall failure. This paper presents the project, its implementation and assessment.

Keywords: Project-based learning, active learning, retaining walls, reinforced concrete structures, geotechnical engineering.

1 Introduction

In France, as elsewhere in the world, alternative teaching methods are on the increase, in particular active learning through project-based learning (APP), which emerged some fifty years ago in Canada. The aim of this form of teaching is to generate learning by carrying out a concrete study, here on a professionally oriented project. This learning process is said to increase and improve the students' commitment, and to ensure a sustainable learning acquisition. Another benefit of the method is the development of cross-disciplinary skills such as project management and collaborative working. However, the disadvantages are that students would have a less rigorous understanding of the fundamentals and that problems can be generated between group members (Airey, 2008), even if it also means learning how to manage conflict. In addition, this type of teaching is time-consuming. These projects can be set up to generate learning of fundamental scientific elements (Ricotier et al., 2017), or to acquire advanced knowledge and expertise (Delage et al., 2006; Gavin, 2011).

In the Geotechnical and Civil Engineering Department of Polytech Grenoble (Engineering School of National Polytechnique Institute of Grenoble - Grenoble Alps University) such projects have been established for several disciplines. This communication presents a project devoted to the learning of the design of retaining walls. The design of a reinforced concrete cantilever wall enables geotechnical engineering and structural mechanics approaches to be tackled in a single project, by checking the external stability of the wall, which is of geotechnical origin, and the internal stability, which is a matter of structural mechanics. The project set up here requires prior knowledge of soil mechanics and the design of reinforced concrete structures, and aims to train students in the design of retaining walls mid-way through their engineering training. Moreover, in order to give students a clear understanding of the possible modes of failure of this type of structure, which are the basis of the design, they are offered a study using an analogue scale model.

2 Project based learning (PBL) principles

PBL is based on three pedagogical principles:

i) Motivation for learning (Saint-Onge, 2008), by confronting the student with a problem similar to those they will encounter in their future professional life,

ii) Collaborative work in small groups, supervised by a tutor,

iii) The generation of generic skills linked to problem solving (rational and analytical approach to a situation, research, structuring and integration of different resources and information to solve the problem), group work and individual work.

During group work sessions, the tutor is not/no longer a teacher but a 'facilitator'. Its role is to lead group discussions, ask questions, facilitate and, if necessary, provide a diagnosis to help each student acquire the knowledge and develop the skills they are aiming for. Question-and-answer sessions can be planned, during which the tutor resumes his teaching role and provides answers to the students' questions, in the form of a course in front of the entire student body.

3 Objectives of the project

3.1 Design of a retaining wall

The aim of the project is for students to acquire skills in designing gravity walls in general, and cantilever walls in particular. The studied case is rather simplistic, as the purpose is to understand the mechanical behaviour, to focus on the general design methodology (in particular, to be able to tackle each possible failure mode, with appropriate sets of partial factors) within a normative framework.

The project consists of designing an inverted T-wall made of reinforced concrete, retaining a homogenous soil mass, in accordance with Eurocode standards (French application standards for the Eurocodes). The case study is depicted on Figure 1. The height and thickness of the wall are given as input data due to the allocated time constraint.

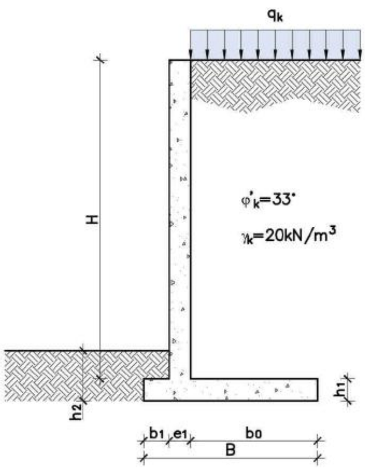

Figure 1. Vertical schematic cross section of the studied wall.

The students are asked to i) determine the geometry of the wall (width B of the footing) in order to ensure the external stability of the structure; ii) determine the reinforcement required to ensure the internal stability of the structure; both parts in accordance with the national application standards of the Eurocodes.

This project has been implemented since 2017, as detailed by Jenck & Ricotier (2019). While the main objectives remain unchanged, the input data change every year, forcing the students to redo the project in case they borrow the outcome from the preceding cohort. For instance, the value of the height of the wall, the soil friction angle, the value of the surface surcharge, the angle of the slope of the retained soil, the case of a cast-in-place or prefabricated walls (which changes the friction under the base of the structure), etc. can be easily varied. This may lead to different dimensional situations and different sets of partial factors. In addition, we insist on understanding and applying the methodology, which students still find difficult to plagiarise from one year to the next. Besides, at the end of the project, the students are required to complete an individual exam (see Section 5). Moreover, a very recent novelty is the implementation of a small-scale model to highlight the mechanisms (see Section 4.4), that also requires the students to do more than simply apply equations (that dedicated program/software can automatically do).

3.2 Acquisition of cross-disciplinary engineering skills

The skills to be acquired by students during this project may relate to the skills reference framework of the 'Commission des Titres d'Ingénieurs', which is the French body responsible for issuing the accreditation of curriculum leading to the award of the engineering degree. The framework contains i) scientific and technical aspects, and ii) personal, organisational and cultural dimensions. For each item, several levels can be reached. For level 1, the skill is not acquired. Acquisition of the skill can be satisfactory from level 2 or 3 upwards.

Concerning the scientific and technical aspects, the skills are:

- Ability to choose and implement tools and methods (level 1 corresponds to "unable", level 4 is "ability to choose, adapt and implement tools and methods with justification of the choices"),
- Ability to identify, analyse needs and constraints, and formalise specifications,
- Ability to present, write and document the solution,
- Ability to find relevant information and to exploit it.

Concerning personal, organisational and cultural dimensions, the skills are:

- Ability to communicate/interact with different interlocutors,
- Ability to integrate into professional life, into an organisation,
- Ability to lead, develop a team, commitment and leadership,
- Ability to take on responsibilities, initiatives, make choices,
- Ability to know yourself, self-evaluation, define your career.

All these items must of course be adapted and put into perspective with regard to the present project. Nevertheless, this part prepares students for the assessments of their future placements and projects, which are now increasingly based on 'skills-based assessment'.

4 Practical implementation of the project

4.1 Students involved and prerequisites

This project is aimed at students in their 2nd year of engineering school (M1 equivalent), in the Geotechnical and Civil Engineering department. The students already have a strong knowledge of soil mechanics, strength of materials, calculation of reinforced concrete structures. They have previously designed structures and applied the principles of the Eurocodes, in particular for foundations (external stability) and reinforced concrete structures such as beams and columns (internal stability). This PBL is offered to students at the end of semester 7, during which they already have attended classes and tutorials in the two subjects "Reinforced Concrete" and "Retaining Structures". However, they haven't dealt yet with the design of gravity walls, nor the specific case of inverted T-walls, but they were taught the basics they need to understand the design concepts: the principle of calculation of reinforcement for 'classic' structures, the concepts of earth pressure and the design of embedded retaining walls. Additionally, the scale model has already been used in lessons to illustrate how embedded retaining walls work.

4.2 General organization

The total duration of the project is three working days (8.45 am to 4 or 5 pm). The three sessions were initially consecutive, but following students' feedback, it is now planned one day a week during three consecutive weeks. The students are in groups of 5 or 6, tutored by a teacher. The two teachers each tutor several groups (3 or 4). All the groups deal with the same project.

A project day always begins with a group session, then alternates sessions of individual work, group work, includes a question-and-answer session at the end of the morning, and a feedback session at the end of the day. The feedback session consists in writing a poster followed by an oral presentation by a group chosen by lottery, then questions and remarks from the teachers, and a discussion. More details on the daily organization is given by Jenck & Ricotier (2019).

The group assessment is based on the poster and presentation, while an individual assessment is scheduled at the end of the project, in the form of a multiple-choice questionnaire (see Section 5).

4.3 Project content and guidance

Students are guided by a booklet that includes the project statement and objectives for each day, including an assessment grid and references to useful books (Ricotier, 2021), courses and standards. Useful standards are provided on the numerical working platform (French standards AFNOR, 2005 and AFNOR, 2014, relative to Eurocode 2 and 7 respectively).

An English translation of the assessment rubric items relative to the first day, more specifically devoted to the geotechnical engineering part, is given on Table 1. The students have this rubric list in their booklet and this should guide them in their progress throughout the session, and so they know what is expected in their report at the end of the day, as well as the technical skills they need to acquire.

Table 1. Items of session 1 assessment grid

Disciplinary objectives	Mark and comments
The various modes of failure of this type of structure are correctly and succinctly presented.	
The calculation model(s) for verifying the external stability of the wall is (are) correctly presented and illustrated with clear, captioned figure(s).	
The verification of the sliding stability is carried out in accordance with the standard, with the relevant parameters explained and analysed qualitatively (heel, various angles, earth coefficients, partial factors, characteristic and design values of the actions).	
The verification of the eccentricity at serviceability limit state (SLS) is made and understood: the calculation model is presented on a clear figure, the article of the standard is quoted, the partial factors utilized are correct and justified, the criterion is verified.	
The verification of the eccentricity at ultimate limit state (ULS) is made and understood: same items as for SLS.	
A solver is used correctly and gives an exact value for the needed heel width b_0 for each of the envisaged failure modes.	
For the final value of the footing width, a table and/or a figure with the actions and their factors, for each failure mode, are given, as well as the results of the regulatory checks.	
The analyses of the failure modes observed on the small-scale model are relevant.	
Quality of visuals	
The language is used rigorously (equations, words, units), spelling and grammar are correct.	
The poster presentation is structured and original.	
Structure of the oral presentation	
The presentation is structured (problem, unknowns, method).	
Quality of oral presentation	
The student masters what she/he is presenting, the visual information is reformulated, additional information is given.	
Oral expression	
The language is correct, the voice volume, the pronunciation and the flow are appropriate, the visual contact is maintained with the public.	
Positive aspects and areas for improvement	

As explained on Table 1, the first session is devoted to the geotechnical engineering part, as the students have to consider the wall external stability. The sessions 2 and 3 are focused on the reinforced concrete wall design regarding the internal stability (not detailed more in this communication). Session 2 is focused on the vertical wall slab, and session 3 covers the internal design of the footing and the complete reinforcement plan for the wall. Geotechnical engineering input is then also needed for these sessions 2 and 3, as the wall has to be designed to sustain actions of geotechnical origin. Through these three different and complementary sessions, students would thus learn about the different calculation models to be used and the choice of partial factors to be used, depending on the different possible modes of failure. Figure 2 shows what is expected in terms of the final result, by drawing up a proposed reinforcement plan. This generally gives students the feeling of having completed a project to the end.

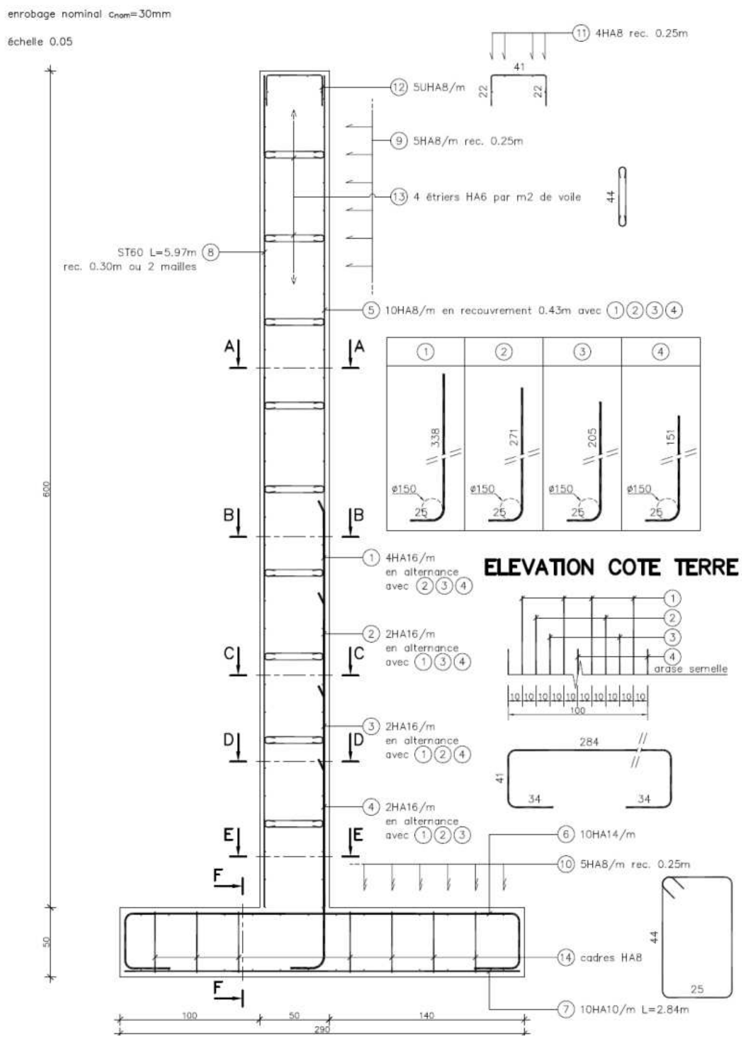

Figure 2. Example of a wall reinforcement plan.

4.4 Qualitative analysis of the failure modes using a scale model

In addition to the design part, an analogical small-scale model is used to highlight the failure modes and their triggering or stabilising factor.

In this model, the soil mass is simulated by a stack of horizontal cylinders of various diameters. Schneebeli (1956) highlighted that this rod assembly behaves as a 2D cohesionless soil by following the Coulomb law. This “Schneebeli” analogical soil has been implemented by several authors to highlight rupture patterns in several geotechnical application (since Biarez, 1962).

For this project, the rod assembly is placed in a rigid frame (0.5 m wide) and a cantilever wall, made of two metal plates welded together, is used. The panel is 200 mm high and the footing is 100 mm wide (20 mm for the toe and 80 mm for the heel). The wall is sufficiently rigid to avoid any risk of internal failure; only external failure modes are studied with this model. The assembly is made of aluminium rods of diameters between 2 and 4 mm and 60 mm long (cf. Figure 3), some of which have an oblong shape. Figure 4 depicts the natural slope of the assembly, with a friction angle of around 22 to 25°. The unit weight is around 20 kN/m^3.

Figure 3. Aluminum rods.

Figure 4. Natural slope of a rod assembly.

The photographs of Figure 5 are given to the students with the task of analysing and discussing the failure modes of the two cases illustrated. The failure state is obtained from "initial" state after removing a few rods downstream of the wall. The scale-model is available to them to reproduce situations, for a clearer view of the kinematics of rupture. NB: for case 2, the heel and toe are deliberately reversed in order to bring out their respective roles. The students are also invited to model additional situations on their own initiative (for instance with a surface surcharge, either upstream or downstream, or with an upstream slope). They must then transcribe their analysis in their report, without any calculation.

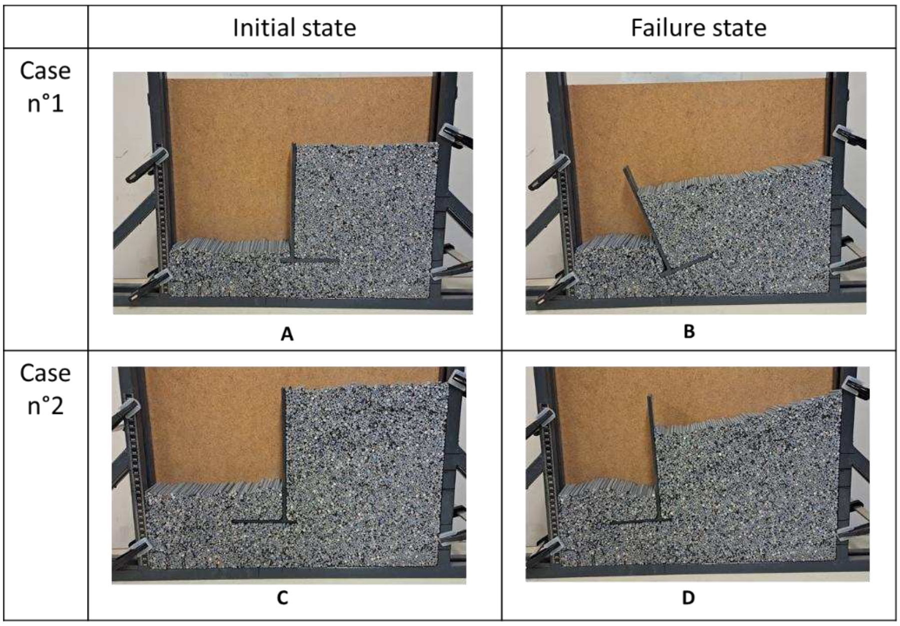

Figure 5. Proposed case studies for the wall external stability using the small-scale model.

This small-scale model implementing the soil analogue is also used during the dedicated lecture as a demonstrator for the embedded walls and their failure modes, in particular to distinguish the modes of failure for cases that are simply embedded or with a support level. A simple steel plate is then used. The model is also used as a demonstrator for geotextile reinforced retaining wall (using fabric strips for the geotextile).

5 Outcome assessment

The students' assessment has evolved during the years, adapting to feedback from experience. At present, the assessment is carried out in the form of the evaluation of the poster of each of the three sessions, using the assessment grid (example in Table 1) of the evaluation of oral presentation if applicable, and of an individual assessment by a questionnaire, at the end of the third and last project days (25 to 30 minutes for the geotechnical engineering part).

5.1 Group assessment

At the end of each session (day), a group selected at random presents its work for around ten minutes (methodology and results) in front of the whole classroom, with the poster projected on a large screen at background. Afterwards, a question-discussion session takes place, to clarify certain points and to broaden the scope of the work, so that learning is not limited to the simplified case dealt within this project. We also look at optimisation levers and existing alternative solutions, with a view to taking into account the environmental impact of the structures and the cost study, even if these points are not detailed in the work requested. During the discussion, students also comment on their acquisition of cross-disciplinary skills through this project, as described in Section 3.2.

5.2 Individual assessment

The individual assessment takes place at the end of the third session through a questionnaire. The questionnaire has multiple-choice questions (MCQ), answers requested in the form of a numerical result to be coded on the copy, and open questions. Each statement has a different set of numerical input data, leading to a different numerical result for each (the aim is to avoid cheating).

The example below dates back a few years and concerns the geotechnical engineering part. The duration was 25 min.

For calculation questions, the numerical result has to be coded on the answer sheet. For MCQ, there can be several correct answers (and there is always at least one). Points are deducted for ticking the wrong boxes twice or more. An automated correction system is used, except for open questions, which must be marked manually by the examiner before scanning (with possibly negative points for an obvious serious error).

As documents are not permitted (calculator only), an appendix is provided, setting out the main equations to be verified for sliding and load eccentricity at the wall base, without additional explanation, as these equations were used during session 1. The parts in italics are those written on the statement.

Part 1

The gravity wall depicted on Figure 6 is considered (cast in place concrete at the wall base). The characteristic value of the unit weight of the material constituting the wall is an input data and is not identical for all statements (varies between 20 and 25 kN/m^3 in steps of 0.5 kN/m^3).

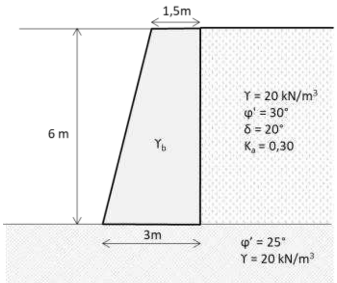

Figure 6. Gravity wall to consider for the evaluation (part 1)

The sliding stability is first considered (ultimate limit state).

Question 1: Determine the design value of the horizontal load on the wall, in kN/m (give the result to the nearest kN/m).

Question 2: Determine the value of the total horizontal resistance $R_{th,d}$ in kN/m (give the result to the nearest kN/m).

Question 3: Calculate the ratio $\frac{R_{th,d}}{H_d}$ (give the result to an accuracy of 1/10).

Question 4: To check slip stability, the ratio $\frac{R_{th,d}}{H_d}$:

A - must be equal to 1
B - must be greater than or equal to 1.35
C - must be less than 1
D - must be greater than or equal to 1
E - none of the above is correct.

Question 5
A - Stability against sliding is assured.
B - Stability against sliding is not assured.
C - The data provided do not allow a conclusion to be drawn on sliding stability.

The verification of the eccentricity of the resultant under the base of the structure is now considered.

Question 6. For this verification:
A - The weight of the wall is an unfavourable permanent action.
B - The soil active earth pressure on the wall is an unfavourable variable action.
C - The weight of the wall is a favourable permanent action.
D - The soil active earth pressure is a favourable permanent action.
E - None of the above is correct.

Question 7: (*e* is the load eccentricity, definition given in the appendix, with the equations).
A - For SLS verification, e must be greater than 0.75 m
B - For SLS verification, e must be less than 0.75 m
C - For ULS verification, e must be greater than 0.06 m
D - For ULS verification, e must be less than 1.40 m
E - None of the above is correct.

Question 8: Indicate the design value of the vertical load transmitted by the wall to be considered in determining the eccentricity at the ULS (give the result to the nearest kN/m).

Question 9: Indicate, in m, the value of the eccentricity obtained at the ULS (to the nearest cm).

Question 10: Indicate, in m, the design value of the vertical load transmitted by the structure to be considered for determining the eccentricity at the SLS (give the result to the nearest kN/m).

Question 11: Indicate, in m, the value of the eccentricity obtained at the SLS (to the nearest cm)

Question 12
A - Eccentricity is checked at the ULS and at the SLS.
B - Eccentricity is checked at ULS but not at SLS.
C - Eccentricity is checked at ULS but not at SLS.
D - The eccentricity is checked neither at ULS nor at SLS.
E - The data provided do not allow a conclusion to be drawn on the verification of eccentricity.

Question 13: In the box below, draw a diagram of the wall showing the eccentricity e, and the actions H_d and V_d, at the ULS. An insert is then provided in the answer sheet.

Part 2

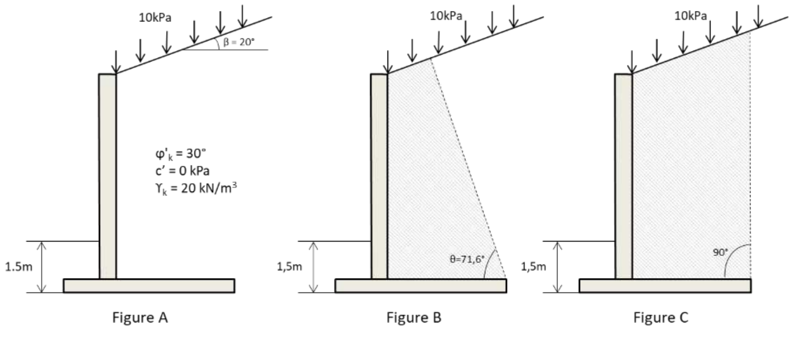

Figure 7. Cantilever wall to consider for the evaluation (part 2).

Question 14: For the verification of the external stability of the wall depicted on Figure 7, the monolithic block to be considered at the rear of the wall:
A - is the one shown in figure B, and the one shown in figure C cannot be considered.
B - is the one shown in figure C, and the one shown in figure B cannot be considered.
C - is either that shown in figure B or that shown in figure C.
D - depends on the mobilisable friction under the base of the structure.

Question 15: To check the internal stability of the wall:
A - The monolithic block shown in Figure B or Figure C (your choice) is considered to determine the actions on the wall vertical slab.
B - The monolithic block in figure B (but not in figure C) is considered to determine the actions on the wall vertical slab.
C - The monolithic block of figure C (but not of figure B) is considered to determine the actions on the wall vertical slab.
D - The monolithic block from figure B or figure C (as chosen) is considered to determine the actions on the heel.

The assessment therefore includes both numeracy and comprehension questions, since numeracy alone is not enough to assess this. In spite of the calculations and the questions of comprehension that seem easy at first sight, the average mark was 7.9/20 (over 40 students) for the assessment example given above (in 2024), which is clearly poor and disappointing. The average mark of the structural engineering part of the same session was 9.2/20, which is not completely satisfactory either. The possible reasons are that it was probably too long (especially if the preparation wasn't serious enough), that the students were tired after a full day of project work, that they didn't seriously rework the concepts seen in session 1, that the marking (with negative points and numerical values to be coded) was too severe. From the students' point of view, the main reason would be the time allocated, which is too short. Another reason is that there is not enough time to learn and understand the geotechnical part, with only one day out of the three of the project (even though the geotechnical aspects are necessary for the 'structure' parts). In the future, serious consideration is being given to increasing the duration of the geotechnical part (with the same objectives) and reducing the duration allocated to the 'structure' part (by removing or lightening the requirements, in particular concerning the details of the constructive provisions for the reinforcement of the wall, which appears to be less important at this stage of curriculum than understanding the fundamental concepts). Unfortunately, the total duration of the project cannot be increased (because of the very tight teaching schedule). Meanwhile, the same required level was subsequently maintained for this assessment (but subject has a different wording and numerical application every year). The average increases slightly each year (similar assessment), as students are warned of the difficulty of this assessment and prepare for it more seriously.

The evaluation has not yet taken place this year, but it is hoped that the more in-depth concepts expected from the analysis of the reduced model will make up for certain shortcomings. If this is not the case, the assessment may be modified for next year.

This poor score is weighted against the collective score, which is generally much better, and the overall mark for the 'retaining structures' module takes into account the assessment of other parts of the programme, with assessment methods other than MCQs.

Additional examples of multiple-choice questionnaire (in French) can be provided to readers on demand.

6 Conclusions

This paper presents an alternative learning method to the traditional lecture and exercise scheme, focusing on the design of a (cantilever) retaining wall for future geotechnical and civil engineers.

Project-based learning allows students to take an active role in their training, thereby increasing their motivation and involvement, which certainly leads to a more secure and lasting acquisition of their knowledge (even if the results of the individual assessment of this project are mixed).

This project also highlights the link between geotechnical engineering and structural design (the stresses to be taken into account for the internal design of the structure are derived from a relevant geotechnical model), whereas these two disciplines were previously taught separately.

Additionally, a small-scale model is considered during the project, which highlights the different modes of wall failure. The latter contributes to the objective of making the students understand the different geotechnical models that have to be considered depending on the mode of failure envisaged, rather than mindlessly applying formulas that software or AI could do for them.

During the discussion with the students at the end of their oral presentation, we get them to think about alternative retaining structures to those made of concrete as mainly considered in this project, or optimisation levers. The need to consider the environmental impact of the structures when designing them is also mentioned. Unfortunately, this aspect is not dealt with in greater depth in this project, which would otherwise be too ambitious for the time available, but we are currently thinking about a way of integrating it nonetheless. These concepts are covered in other modules of the curriculum. The cost study is not addressed in this project either, which is limited solely to the technical dimensioning aspect.

To conclude, this type of alternative teaching requires a great deal of commitment on the part of the teaching staff (setting up and running the course), but provides a certain satisfaction in seeing the students more involved in their training and in an effective learning situation, while strengthening the cohesion of the teaching team.

Acknowledgements

The teachers acknowledge former student Thibaud Exertier (graduated in 2024) for building the frame of the small-scale model, under the guidance of our colleague Christophe Dano; and the Technical University Institute of Grenoble for the donation of a batch of aluminium rods (soil analogue). The authors are also grateful to the reviewers for their constructive comments.

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