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Exploring geotechnical design in teaching using parametric studies and an API with numerical models

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ABSTRACT: This paper describes an item of undergraduate coursework that is set in the context of the design of an anchored sheet pile wall as part of a module in Geotechnical Design. In this coursework students are required to optimize components of the anchor/wall system, determine worst case loading scenarios and undertake parametric sensitivity analyses using the numerical software tool LimitState:GEO . One issue that affects a proportion of students is that they do not fully validate their models prior to undertaking parametric studies, thus incurring additional work through repetition of the parametric studies with a revised model. This paper gives an overview of the coursework, areas that students find challenging and describes updates to the exercise that allows automation of the optimization and parametric studies via an API. This allows a larger parametric study space to be investigated and the incorporation of basic reliability analysis.

KEYWORDS: parametric study, API, design, optimization.

1 INTRODUCTION

This paper describes an item of undergraduate coursework that is set in the context of the ULS design of an anchored sheet pile wall as part of a module in Geotechnical Design.

In this coursework students are required to optimize components of the anchor/wall system, determine the worst-case loading scenarios and undertake parametric sensitivity analyses using the numerical software tool LimitState:GEO (LimitState 2021). LimitState:GEO provides a rapid ULS analysis capability based on the Discontinuity Layout Optimization (DLO) method (Smith & Gilbert, 2007). This makes it well suited for interactive use by students, enabling them to ask 'what if' type questions, understand how parameters influence system behaviour and visualize the extent of failure mechanisms - something which is less straightforward with some other retaining wall software and hand calculations.

One issue that affects a proportion of students is that they do not fully validate their models prior to undertaking parametric studies, thus incurring additional work through repetition of the parametric studies with a revised model. This paper gives an overview of the current coursework, areas that students find challenging and describes updates to the exercise that allows automation of the optimization and parametric studies using, for example, Python via an Application Programming Interface (API). This allows a larger parametric study space to be investigated and the incorporation of basic reliability analysis.

2 CURRENT DESIGN EXERCISE

2.1 *Problem parameters*

The structure of the coursework has evolved over a number of years and aims to strike a balance between achieving key learning objectives, while aiming to target the allocated timetabled and independent study time for the average student. The problem parameters are varied each year to ensure that each new group of students has a different problem to investigate. Typical parameters are given in the following sections.

The sides of an 8-10m deep excavation in sand are to be supported by an anchored sheet pile wall as shown in Figure 1. For simplicity, a deadman anchor is specified and the position at which the anchor connects to the wall is also pre-specified. The soil's friction angle, dry and saturated unit weight are given, together with a value to be assumed for the interface friction between wall and soil.

An example LimitState:GEO model file is provided for download and may be used and adapted by the student for the coursework. However, the provided model does not match the design brief precisely and it is up to the student to adapt the model and ensure that the parameters are as required for the specified design. This ensures that students gain early familiarity with the software and 'own' the model. Despite this, it is observed that a small minority of students do not read the brief and start modelling with the provided model thus wasting time, despite clear instructions in the brief.

The task is broken into three parts, the first is to determine the baseline 'optimal' design (see Section 2.3.1), the second is to look at the effects of parameter/assumption variation, and the third is to undertake a hand calculation check.

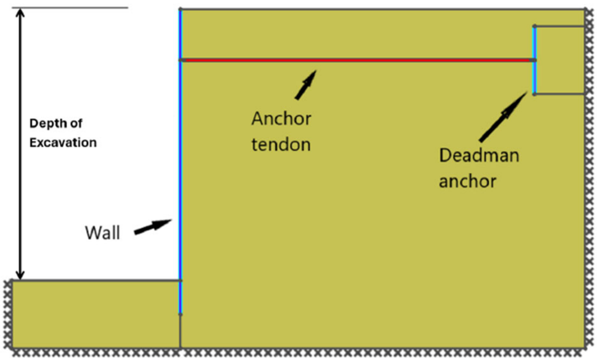

Figure 1. Problem scenario

2.2 *Learning Objectives*

The primary learning objectives for the coursework are as follows:

1. Demonstrate approaches to tackle multi-parameter design.
2. Demonstrate insight from observed failure mechanisms:
   a. Determining favourable and unfavourable actions,
   b. Determining critical spacing between wall and anchor.

3. Describe the margin of safety and how this is achieved through use of partial factors and use of input and output factoring.
4. Ability to undertake parametric studies and determine parameter sensitivity.
5. Validate numerical models through hand calculations and explain differences in results.
6. Explain the precision to which values need to be computed.

2.3 *Part I: Baseline task*

2.3.1 *Multi-parameter design*

In principle, students would be asked to determine the most economic design for the complete system, including wall, anchor tendon and anchor plate. However, this would require multi-objective optimization which would be time consuming by hand.

Instead, students are asked to optimize components of the design with a clearly specified order of priority. They can then realise that each component can be studied in isolation in turn while temporarily over specifying the other components.

The primary task is defined as finding the shortest vertical length of wall, using a specified wall section, that complies with the Eurocode 7 VC3 + M2 and VC4 + M1 partial factor sets (BSI 2024) against Ultimate Limit State (ULS) failure. They are directed to the manufacturer's handbook (ArcelorMittal 2022) to identify wall section parameters.

For simplicity students are told to assume that the anchor tendon and anchor plate contribute negligible extra cost, so that they can design these to provide the largest support forces required for optimal wall design. They are then asked to determine the following parameters (in the order of priority below) for the final design:

1. shortest vertical length of anchor (assuming a rigid anchor).
2. shortest horizontal connection length between wall and anchor.
3. lowest anchor/wall connecting tendon tensile (rupture) strength.

An interim submission is required to encourage students to maintain progress in line with the schedule and provide feedback as to whether their approach is appropriate without giving answers. They are asked only to submit four numerical values as follows:

- wall vertical length (m)
- anchor vertical length (m)
- anchor tendon length (m)
- required anchor tendon strength (kN/m)

To obtain the wall and anchor vertical length requires some trial and error varying the wall length (in conjunction with an oversized anchor), and then having established a value for this, varying the anchor length until the system is on the point of failure.

There are no marks associated with this interim submission. However almost all students submit their results. The incentive is that the information will be circulated as graphs to all students so that everyone can check their Part I results against the rest of the group.

Students are told that, if necessary, they may revise their calculations before starting Part II, i.e. that they do not necessarily need to use their interim submission values for their final report.

An example feedback graph is provided in Figure 2. Typically, the largest proportion of students get the correct solution so this can be highlighted. However, due to small numerical tolerances propagating through the stages of the solution determination, there tends to more scatter for the lower priority parameters.

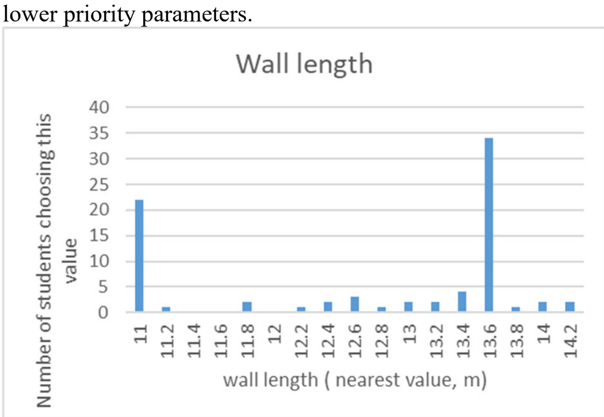

Figure 2. Example feedback after Part I.

2.3.2 *Favourable/unfavourable loading*

Students are informed that it is possible that a surcharge load of up to e.g. 10kN/m^2 could be applied over any width or series of separate widths on the horizontal surface of the soil body retained by the wall, between the locations 2m to 35m from the wall top. This surcharge could be, for example, the temporary placement of building materials or construction plant.

Students then are asked to determine whether this load is variable or permanent and also if it is favourable or unfavourable and to determine the worst-case positioning. They are told that favourable actions oppose failure, and unfavourable actions assist failure and are asked to look at the animated failure mechanisms provided by the software to see where these situations occur.

The students therefore first have to determine that the load is variable (so that the factor on favourable actions is zero). This then means that only the unfavourable location is required. Many students simply place this uniformly over the specified range 2m to 35m. However, those that examine the mechanisms, e.g Figure 3, determine that it is unfavourable behind the wall, and behind the anchor, but not in front of the anchor. Using the software they can determine the exact extents. This can involve a small amount of iteration since placement of the load will modify the extent of the failure zone, but because the load is small, the change is not significant. The aim is for students to appreciate the general principle and that it can be applied to any problem type.

2.3.3 *Spacing between wall and anchor plate*

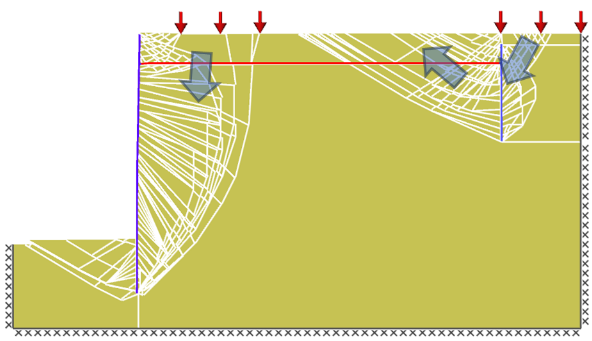

Figure 3. Failure mechanism with simultaneous, but separate failure of anchor plate and wall (wide spacing). Block arrows added to show direction of soil movement in animated failure mechanism.

To determine the optimal anchor tendon length requires varying the horizontal position of the anchor plate and observing the mechanisms, for example as shown in Figure 3 where there is no interaction of the failure mechanisms generated by the wall and the anchor and in Figure 4 where there is clear interaction.

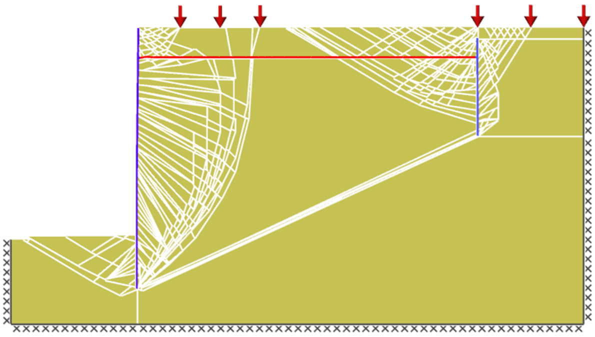

Figure 4. Failure mechanism with combined failure of anchor plate and wall, introducing a component of combined sliding (close spacing).

The optimal location is where the mechanisms are just at the point of combining, but students can observe that slight overlap has minimum effect and appreciate that it is primarily the weight of the wedge in front of the anchor and behind the wall that determines the respective loads. Placing the anchor very close to the wall generates a clearly ineffective solution, as shown in Figure 5. The tensile load in the anchor tendon can be directly determined from the software solution.

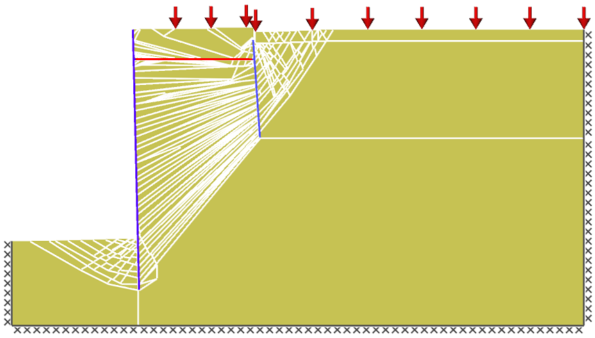

Figure 5. Failure mechanism with anchor plate positioned so close to the wall that it is ineffective and has become part of the wall failure mechanism.

2.4 *Part II: Parametric studies*

Having established the baseline design and been given the opportunity to check that they have the correct dimensions, the students are then asked to undertake some sensitivity studies and plot graphs of a relevant parameter against the parameter studied. The relevant parameter could be a design dimension or a factor of safety. In the latter case, students are asked to be clear what they mean by factor of safety (e.g. applied to a load, a strength or a dimension). These parametric studies are changed each year. Some examples are given in the following subsections.

2.4.1 *Sensitivity to overdig*

It is well known that anchored walls in granular soils are quite vulnerable to overdig and this is normally included in the design calculation. Here the students are asked to explore how the factor of safety changes as the level of the soil on the excavated soil is lowered and to discuss why they get the results they do.

2.4.2 *Water table rise*

A simple scenario involving a potential flooding event, where a horizontal water table could rise to a specified height above the excavation level, is considered. Students are asked to explain qualitatively the results that they obtain.

2.4.3 *Assumed interface friction angle sensitivity*

A typical graph of required wall length vs interface friction ratio that can be determined from the software is given in Figure 6. Students see that the sensitivity changes significantly at a ratio of about 0.5 and are asked to comment on how accurate they think the initially specified interface angle of friction is required to be.

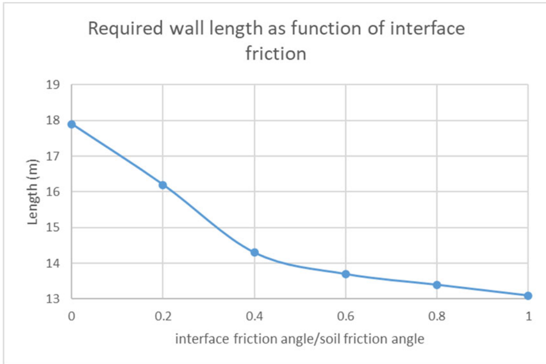

Figure 6. Example of variation of wall length vs interface friction angle ratio.

2.5 *Part III: Hand calculations*

Students are directed to their lecture notes/course textbooks to undertake a typical anchored wall stability calculation using Rankine earth pressure coefficients for a simplified scenario without surcharge. If they have looked at the sheet pile manufacturer's handbook (ArcelorMittal 2022) earlier in the project they will also have seen that this contains several worked examples.

If they get the calculation correct, they will typically find that there is still a discrepancy between the numerical model and the hand calculation and this facilitates discussion around the accuracy of models in general.

3 ASSESSMENT

In the preceding years of their course, students undertake mini-projects in geotechnics, coupled with laboratory experiments to determine soil properties which they then use in simplified design calculations. For ease of marking students submit their work using a 'fill in the blanks' type report with spaces for plotting graphs, entering calculations or writing brief discussions, which gives them basic guidance on core elements of a report structure.

Item	Marks	Required content
Summary	4	Give an overview of the key points from **whole** report (including introduction, key results and conclusions). The reader should be able to get the an overview of the report from reading the summary only. No diagrams should be used in the summary. The summary should include qualitative and quantitative data as appropriate.
Problem Specification	4	Provide a **diagram** illustrating the problem and the key relevant **parameters** (this could be in text or in annotations on the diagram). It is important to give the reader who has not seen the problem before enough information so they could **repeat** the work. It is also important to confirm to a reader who has seen the problem specification that you have interpreted that specification correctly.

Figure 7. Example of assessment specification.

In Year 3, where this coursework is set, the expectation is that students write a report themselves, but this is still structured using a guided report specification and marking scheme. The aim is to get students to appreciate why they are writing specific parts of a report, as for example, shown in Figure 7, where repeating the design specification back ensures the reader is confident the student has read the brief correctly and that the reader can reproduce the results if necessary.

4 FUTURE UPDATES – API USAGE

4.1 *Automating current exercise*

Linking and/or automating software runs via APIs to facilitate rapid workflow is an increasing feature of industry usage, often using Python as the linking tool (Yogatama & Tirta 2021).

The exercise will be updated to encourage students to use an API or command line interface, via Python scripts or a Windows Batch file to generate sets of results. Python is increasingly being taught as part of many University undergraduate courses including the course at Sheffield.

There is a risk that the use of APIs will separate the student from interacting with the software and lose both the inherent learning experiences and increase the prospect for errors. Students will only be introduced to the use of the API after Part I of the exercise. They can then use this to:

1. Quickly re-run models if they found their Part I results were out of line with other students.
2. Undertake the parametric studies in Part II.

Students will be encouraged to either use pre-prepared spreadsheets or Python directly to plot results so that their workflow is sped-up. Based on experience with the current project, it will be essential to provide example batch/Python/spreadsheet files for students to adapt since there is quite a wide variation in student ability with such tools.

Part of the assessment will include asking the students to outline the advantages and disadvantages of using an API and how they avoided making errors by not directly interacting with the software.

4.2 *Simple reliability analysis*

The use of APIs also facilitates the use of simple reliability approaches such as Monte-Carlo which become tractable with fast running software such as LimitState:GEO. Later in the module students cover reliability principles and this can be illustrated through examples in lectures and through tutorial exercises using an API with the software which students will now be familiar with from the coursework exercise.

5 DISCUSSION

5.1 *Current exercise*

Feedback on the current exercise has generally been good over the years. Students appreciate the experience of learning and using new software, the ability to use it interactively, get quick results and the ability to visualize the animations of the failure mechanisms. A small subset of students achieves almost 100% marks on the coursework. However, overall, there is quite a wide distribution of marks, with those at the lower end clearly not having allocated enough time to do the exercise.

In principle and with careful thought and planning, students should be able to determine the optimum Part I configuration using between 15 and 20 runs of the software, where each run is completed in a matter of seconds, rather than minutes. In practice students end up taking many more runs due to trial and error and learning the optimal process. It has also been observed that, for many students, there is a temptation simply to 'dive in' and use the software without much pre-planning and thought despite encouragement to think first. Hopefully they learn from experience that this is not a good strategy.

As mentioned in Section 2.4, the problem and parametric studies are varied each year to reduce the risk of solutions being handed down year to year and there is plenty of scope to vary scenarios around the core theme.

5.2 *Updates incorporating automation*

Some general issues around the use of technology in geotechnical education are discussed by Rehman, 2023. One of the key challenges in updating this exercise will be to ensure a balance between the manual and automated use of the software as use of the latter can lead to a loss of understanding. From current experience there will always be a subset of students who will want to take the easy route. Thus, as described, the aim will be to encourage manual use in Part I and automated use in Part II, while explicitly exploring the above challenge as part of the assessment.

Looking even further ahead, AI is being increasingly used in industry, and it is highly likely that an AI could be employed to undertake significant parts of the exercise with little interaction by the student. These issues are beyond the scope of the current paper but are certainly ones being actively discussed in higher education (e.g. Tophel et al. 2025), ensuring that students develop the right skills to effectively use modern technology while still developing the inherent skills to be an effective engineer able to tackle the civil engineering challenges of the future.

6 CONCLUSIONS

This paper has provided an overview of a current numerical modelling exercise for the design of an anchored sheet pile wall that addresses a varied set of learning objectives through interactive use of geotechnical analysis software. It has outlined some of the challenges and solutions developed during the evolution of this exercise over a number of years.

The paper has also discussed updates to the exercise facilitated by APIs and some of the opportunities and challenges presented therein.

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