Soils and Rocks

An International Journal of Geotechnical and Geoenvironmental Engineering

www.soilsandrocks.com

ISSN 1980-9743
ISSN-e 2675-5475

Digital tools used on the teaching-learning process in geotechnical engineering

Carolina Crissafe dos Santos Lemos[1#], Luiz Otávio Fontes Dias[1], Paulo Sérgio de Almeida Barbosa[1], Eduardo Antonio Gomes Marques[1], Roberto Lopes Ferraz[1], Gustavo Henrique Nalon[1]

Article

Keywords
Information and communication technologies
Teaching-learning process
Geotechnical engineering
Digital tools
Software
Geotechnical engineering education

Abstract

This article presents the incorporation of information and communication technologies on the teaching-learning process of geotechnical engineering to improve the quality of education and provide practical knowledge to civil engineering students. The content of this paper is divided into three main modules, which are: Treatment of laboratory tests results, Slope stability and Rock mass stability. For this, some software were used, including 2D limit equilibrium stability analysis, stability analysis of rock wedges and a dynamic mathematics, to obtain and analyze soil shear strength parameters, among others. Furthermore, a digital tool was developed to analyze the results gathered in compaction, one-dimensional consolidation, and direct soil shear tests, in order to clarify the relationship between theoretical concepts and practical results of the tests and analyses and to help students on doubts, in addition to increase their interest and motivation to perform the complete interpretation of the collected data. The activities were conducted in classes of geotechnical disciplines of the undergraduate course in Civil Engineering at the Federal University of Viçosa, aiming to promote active learning and improve teaching quality. Based on the results of an applied feedback questionnaire, it was observed that most students were satisfied with the resources used in the classroom, demonstrating that the implemented digital tools work as a didactic instrument that facilitates learning and comprehension of practical problems, in addition to enabling the resolution of several geotechnical engineering problems much more quickly and efficiently.

1. Introduction

Quality education is one of the Sustainable Development Goals of the United Nations 2030 Agenda (United Nations, 2023), which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. In this sense, digital technologies have been recognized as a fundamental tool to achieve this goal, providing an excellent opportunity to assist students in establishing connections between the theoretical concepts studied and practical problems (Haleem et al., 2022).

Geotechnical Engineering involves problems of significant complexity, which require a solid understanding of theoretical concepts to support high-quality engineering projects. Therefore, the use of digital tools in the teaching-learning process on geotechnical engineering is becoming increasingly important. Through specialized software, it is possible to carry out more accurate and elaborated analyses, simulating situations that would be much more laborious without the aid of these tools and would require more time and resources. Furthermore, digital tools can help to prepare students for the geotechnical industry, by providing them with practical skills that are highly valued by employers.

In this context, the implementation of some interactive digital tools has been proposed to assist undergraduate students in geotechnical disciplines of the Civil Engineering course at the Federal University of Viçosa in order to assist the students to perform, analyze, and interpret results related to different laboratory tests, slopes stability studies and rock masses characterization and analyses, and flow studies.

[#]Corresponding author. E-mail address: carolina.crissafe@ufv.br.
[1]Universidade Federal de Viçosa, Departamento de Engenharia Civil, Viçosa, MG, Brasil.

Submitted on May 12, 2023; Final Acceptance on January 22, 2024; Discussion open until August 31, 2024.

https://doi.org/10.28927/SR.2024.004923

From this experience, it will be discussed whether this approach could contribute to the improvement of students' learning, promoting a deeper understanding of the concepts studied in the classroom, in addition to developing skills in the use of digital technologies applied to geotechnical engineering. Finally, the perceptions of students regarding the use of these tools will be presented, obtained through a feedback questionnaire.

2. Materials and methods

Table 1 presents the geotechnical disciplines of the Civil Engineering undergraduate course in which digital tools were applied, their regular semester of offering and the syllabus for each one.

2.1 Treatment of laboratory tests results

Performing laboratory tests is essential for understanding the properties of materials used in geotechnical works, enabling the prediction of soil and rock behavior when subjected to various field conditions. In addition, the correct interpretation of these tests is crucial for the precise characterization of materials, allowing the choice of appropriate parameters for the project.

Thus, in order to facilitate the understanding and application of the concepts studied in the disciplines, a practical approach with demonstrations of the procedures was proposed. For this, the use of two main software was implemented: Microsoft *Excel*® and *GeoGebra*, a free software.

Excel was applied more widely in the "Soil Mechanics I" course to exemplify concepts, facilitate calculations, and demonstrate more quickly some correlations between soil physical index parameters. In addition, its use was essential in laboratory classes in the "Soil Mechanics I and II" courses, where it became a very useful tool for teaching the processing of data obtained from tests such as Consolidation, Direct Shear, and Triaxial Tests.

GeoGebra was primarily used to promote interaction with graphical solutions to define equations that would typically be difficult to visualize and draw in the classroom, such as the Mohr-Coulomb diagram, the graphical determination of soil shear strength parameters, and the determination of normal and tangential stresses on the failure plane. Its use was added to slide presentations and to the classic blackboard drawing tools in which only static scenarios could be demonstrated, which limit teaching to pre-defined situations in lesson planning, making it difficult to adapt to questions that can arise in the classroom. The objective was to make the solutions already in use more visual and interactive, so that students could have greater interest, focus, and understanding of the presented concepts.

Furthermore, encompassing the teaching of several of the previously listed topics, a custom application was developed with joint effort from students and professors, named "Soil Physical Indexes". This application was developed in Adobe® Flash Professional CS5 language and ActionScript® code, and although considered simple compared to commercial software, it contributed for a practical and friendly learning environment to be created. Content related to theory, definitions of concepts, animated examples, exercises and demonstrations of practices in laboratories were implemented on it. This application was designed to be made available to students of the Civil Engineering course at the Federal University of Viçosa, acting as a study tool for them. This tool brings together in one single place the possibility of reviewing and applying concepts seen in the classroom, with the possibility of doing exercises of different levels of difficulty and checking the results.

Table 1. Disciplines in which digital tools were applied.

Discipline	Semester	Discipline syllabus
Engineering Geology	4th	Main geological phenomena. Stratigraphy. Structural geology. Geological-geotechnical properties of geological formations. Weathering. Technological properties of rocks. Underground investigation. Hydrogeology. Tunnel geology. Dam geology.
Soil Mechanics I	5th	Soil mechanics and engineering. The soil from an engineering perspective. Index properties of soils. Soil structures. Classification and identification of soils. Stresses acting on a soil mass. Soil permeability. Compaction.
Soil Mechanics II	6th	Water flow through soils. Soil compressibility and consolidation. Shear resistance of soils.
Earthworks	9th	Exploration and soil sampling for geotechnical projects. Slope stability and retaining structures in soils. Retaining structures. Earth pressure on support structures. Stability of retaining structures. Lowering of the water table.
Earth and rockfill dams	Optative	Introduction. Dams. General aspects. Earth and rockfill dams. Small earth dams. Geological investigations. Geotechnics of foundations. Study of materials to be used in construction. Laboratory tests for design purposes. 'In situ' tests on the dam body. Percolation in earth and earth-rockfill dams. Slope stability analysis. Monitoring during construction and operation. Understanding seismic effects.
Introduction to Rock Mechanics	Optative	Concepts in rock mechanics. Minerals, classification, weathering and index properties of rocks. Strength and deformability properties of rocks, discontinuity and rock masses. Flow in rock masses. Slope stability. Rheological behavior of rocks. Underground excavations. Instrumentation and monitoring.

2.2 Slope stability

Performing slope stability analysis is fundamental in several applications in Geotechnical Engineering. Therefore, it is extremely important that the student understands both the theoretical content involved in the solutions, as well as the functionalities of slope stability analysis software, which will be essential in their professional practice.

Thus, during the classes of the disciplines “Earthworks” and “Earth and Rockfill Dams” of the Civil Engineering course at the Federal University of Viçosa, software for slope stability analysis using the Limit Equilibrium Method and for percolation analysis through computer simulations were used to illustrate theoretical concepts, to present practical exercises to solve real problems, and to develop geotechnical projects using these software tools. For this purpose, the *Slide2* software from Rocscience® and *Slope/W* and *Seep/W* from the *GeoStudio* package by Seequent® were used.

Initially, in the introductory part of the discipline “Earthworks”, contents regarding landslides were explained, involving the main types of landslides and its possible causes. Afterward, the types of failure and the main methods used for slope stability analysis, in terms of strength and permeability, were addressed. From this, the professor instructed the students on the most commonly used slope stability software, explaining in detail the functioning and use of these programs. During the classes, the student version of the *Slope/W* and *Seep/W* software from the *GeoStudio* package, which is available for free download on the Seequent® website, was used. In addition, a UFV’s student license for the *Slide2* software from Rocscience® was provided to each student in the course, and it was up to the student to choose which software to use for the activities, according to their preference.

In order to demonstrate the practical use of the softwares for slope stability analysis, in addition to aid in the understanding and memorizing of theoretical concepts, several exercises were proposed. Among them, the analysis of stability of a partially saturated heterogeneous slope was performed to determine the potential surface of failure and the global safety factor using deterministic methods based on the limit equilibrium, such as those proposed by Bishop (1954), Spencer (1967), and Morgenstern & Price (1965). The objective of this activity was to evaluate whether the simplified Bishop method, which only considers the effect of normal forces between slices and satisfies the moment equilibrium, provides similar results to the Spencer and Morgenstern & Price methods, which consider the effect of normal and shear forces between slices and satisfy the equations of statics related to moment and force equilibrium.

In addition, another important activity proposed was the performance of percolation analysis of a retaining wall with a vertical drainage system, in order to better visualize the drainage behavior inside the soil mass with the retaining structure. To carry out this activity, the student could choose which software to use to perform the analysis, according to their preference. Furthermore, in the final part of the “Earthworks” discipline, an evaluation was proposed regarding the feasibility of constructing a gabion retaining wall to contain a certain soil mass. In this evaluation, the lateral earth pressures should be calculated, as well as the global stability analysis of the wall-soil system, using one of the analysis methods based on the limit equilibrium theory and a slope stability program of the student’s preference.

In the discipline “Earth and Rockfill Dams”, the same software mentioned earlier were also used. Initially, theoretical concepts related to dam construction were discussed, including aspects related to compacted embankments, shear strength, percolation, drainage systems, among others. After exposing all the theoretical content, a dam inspection project was proposed for a dam located in the state of Minas Gerais, Brazil, including a technical visit and the preparation of a technical report containing stability and percolation analyses of the dam. To carry out these analyses, a slope stability software of the student’s choice was used.

2.3 Rock mass stability

Just as the stability analysis of soil slopes, stability analysis of rock masses is an essential activity to be carried out in many geotechnical projects, such as dams, open-pit and underground mine slopes, tunnels, highways, foundations, and several other applications.

Software for stability analysis of rock masses are powerful tools to predict material behavior under field conditions. One of the widely used techniques to perform this prediction is the kinematic analysis based on stereographic projection. This technique allows the analysis of the orientation of fractures and faults present in rocks, through angular relationships between lines and planes in space, using a projection of a sphere onto a plane (Marques & Vargas Júnior, 2022), enabling the identification of fracturing patterns that may affect the stability of the rock mass.

Therefore, the software *Dips* from Rocscience® and the free software *Stereonet* were used in the “Engineering Geology” course of the Civil Engineering course at the Federal University of Viçosa, to predict possible planar, toppling or wedge failures in rock masses. In addition, the Rocscience® software *Rocplane*, *Swedge*, *Unwedge* and *Toppling* were used in the “Introduction to Rock Mechanics” discipline to evaluate the stability of discontinuity planes in rock masses using the Limit Equilibrium Method.

The “Engineering Geology” course was divided into two types of classes, theoretical and practical. During the theoretical classes, contents were covered regarding structural geology, geological-geotechnical properties of geological formations, factors that influence the behavior of rocks, and various applications in geotechnical works. In the practical classes, concepts about geological maps and sections, as well as stereographic projection were studied.

On the practical classes several exercises of plotting planes, lines and poles were done using the Schmidt-Lambert net with equal-area projection, based on the information that characterizes the attitude of each plane. From this, the professor of the discipline instructed the students on the most widely used stereographic projection analysis and kinematic analysis software, teaching in detail the operation and use of these programs. During the classes, the *Stereonet* software, which is available for free download on the internet, was used. In addition, a student license to use the *Dips* software from the Rocscience® company was provided to each student of the course, leaving it up to them to choose which software to use for the proposed activities.

With the objective of demonstrating the practical use of stereographic projection, in addition to helping the understanding and consolidation of the theoretical concepts studied, a project was proposed to evaluate the feasibility of constructing a highway, whose route required cutting through a fractured rock mass to overcome a certain elevation. For this purpose, data on the attitudes of 74 discontinuities planes obtained from a real geological mapping were provided, as well as two possible cutting plans for the construction of the road, so that students could evaluate the possible types of failure for each proposed slope and determine the ideal option. To perform these analyses, a stereographic projection analysis software of the student's choice was required.

In the "Introduction to Rock Mechanics" course, concepts were addressed regarding the main fields of application, including topics on geomechanical classification, rock alterability, flow in rock masses, rock excavations, and stability analysis of rock slopes, among other important aspects. In order to present the concepts related to rock mass stability more clearly, several activities were proposed to evaluate the possibility of planar, toppling, and surface and underground wedge-type failures using *RocPlane*, *RocTopple*, *Swedge*, and *UnWedge* software, respectively. In these activities, students had to assess the stability of the rock masses under study, and if they did not meet the necessary safety factors, a stabilization solution for the mass should be proposed.

2.4 Feedback questionnaire

In order to obtain an overview of the impacts of the implementation of digital tools in the teaching-learning process, an electronic questionnaire was developed for the Civil Engineering undergraduate students who have already taken disciplines in the area of Geotechnics. Thus, through this questionnaire, students were able to anonymously report their individual evaluation on how the use of these digital tools has impacted their learning process.

3. Analysis and results

3.1 Treatment of laboratory tests results

Figure 1 and Figure 2 show the interface of the "Soil Physical Indexes" application developed at the Civil Engineering Department of Viçosa Federal University and used in the "Soil Mechanics I" discipline. The example shown portrays the verification of the soil physical indexes calculated in two specific exercises of the course.

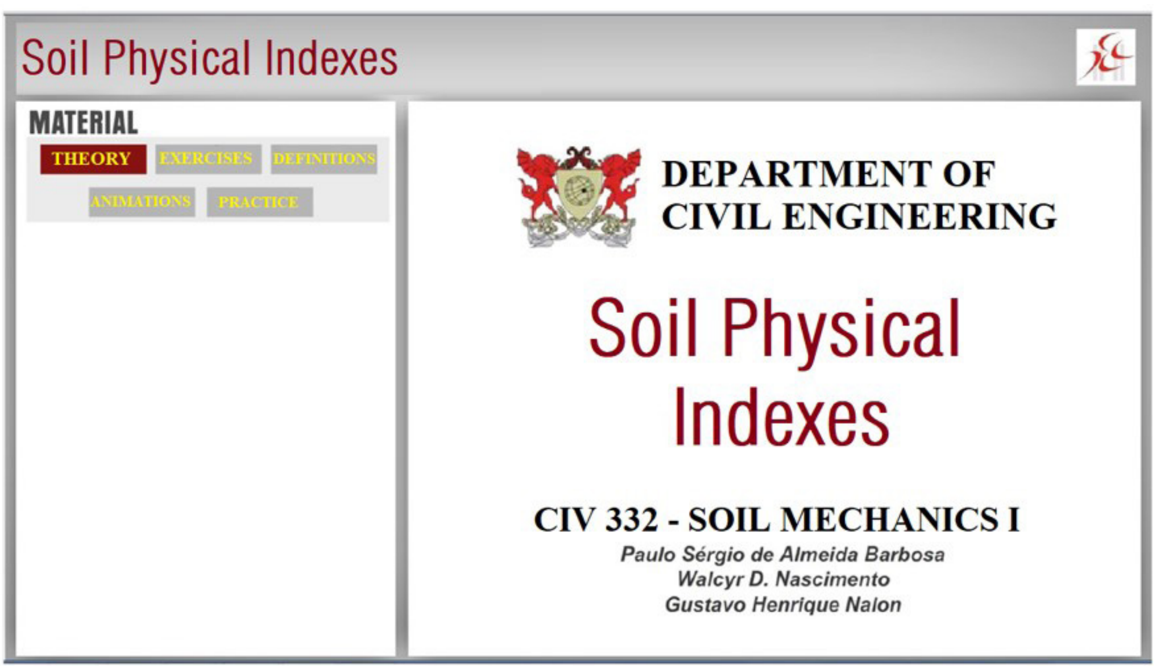


Figure 1. Application interface with available features. Adapted from Nalon et al. (2013).

The use of the resources of this application has proved to be a very important tool to help the fixation of the knowledge of the soil physical indices, since after the classes, the students were able to revise, exercise, check and often solve doubts about the themes studied. In addition, this tool also helped explain and review the subjects covered in practical classes, as shown in Figure 3.

Figure 4 shows two graphs generated from data obtained in a direct shear test, with pre-consolidation stresses of 50, 100, and 200 kPa, aiming to illustrate the process of interpreting the results of laboratory tests in Excel, in the discipline of "Soil Mechanics II". From the visualization of these graphs, it was possible to guide students through the interpretation of each element, such as the inclination of the lines, deformation stages, and failure stresses of the samples, as well as to correlate them with the preconsolidation stresses. This graphical resource, when used in various tests, samples, and soil types, demonstrates the different situations that future professionals may face.

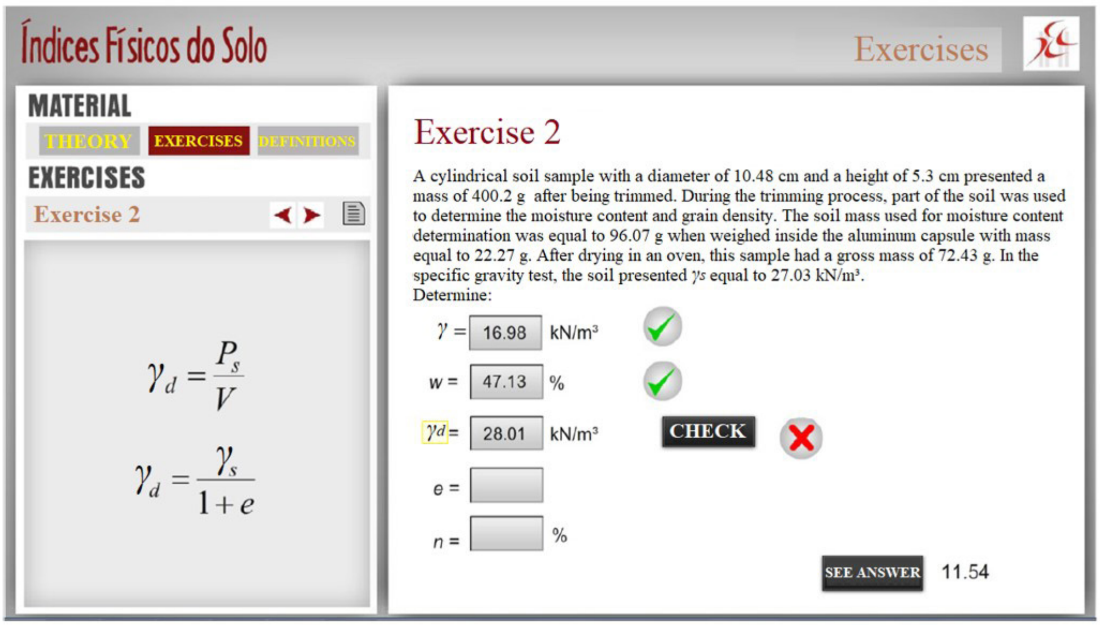


Figure 2. Application exercises functionality. Adapted from Nalon et al. (2013).

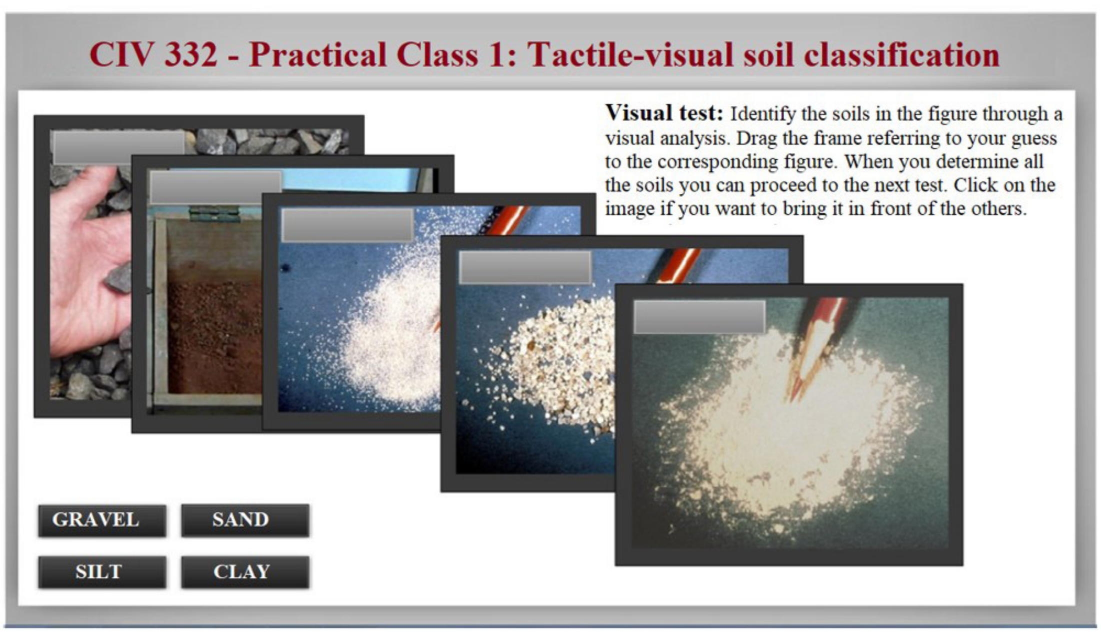


Figure 3. Animation of lab practice functionality. Adapted from Nalon et al. (2013).

Thus, the contribution of this tool in refining and interpreting laboratory tests data could be observed, exercising an easy and practical way to provide data recording, graphical representation, and obtaining useful parameters for future analyses.

Figure 5 shows some useful results obtained in tests such as direct shear in the *GeoGebra* graphical solution. The bars shown above the graph represent sliders of soil parameter values, which, once changed, modify the graph format, illustrating the correlation between them.

This tool represented a means by which the professor of the discipline "Soil Mechanics II" could demonstrate in a more visual way the Mohr-Coulomb diagram, the determination of soil shear strength, and stress trajectories. Moreover, it was very useful in helping students to better visualize the theoretical concepts related to this subject, contributing to the improvement of the teaching-learning process.

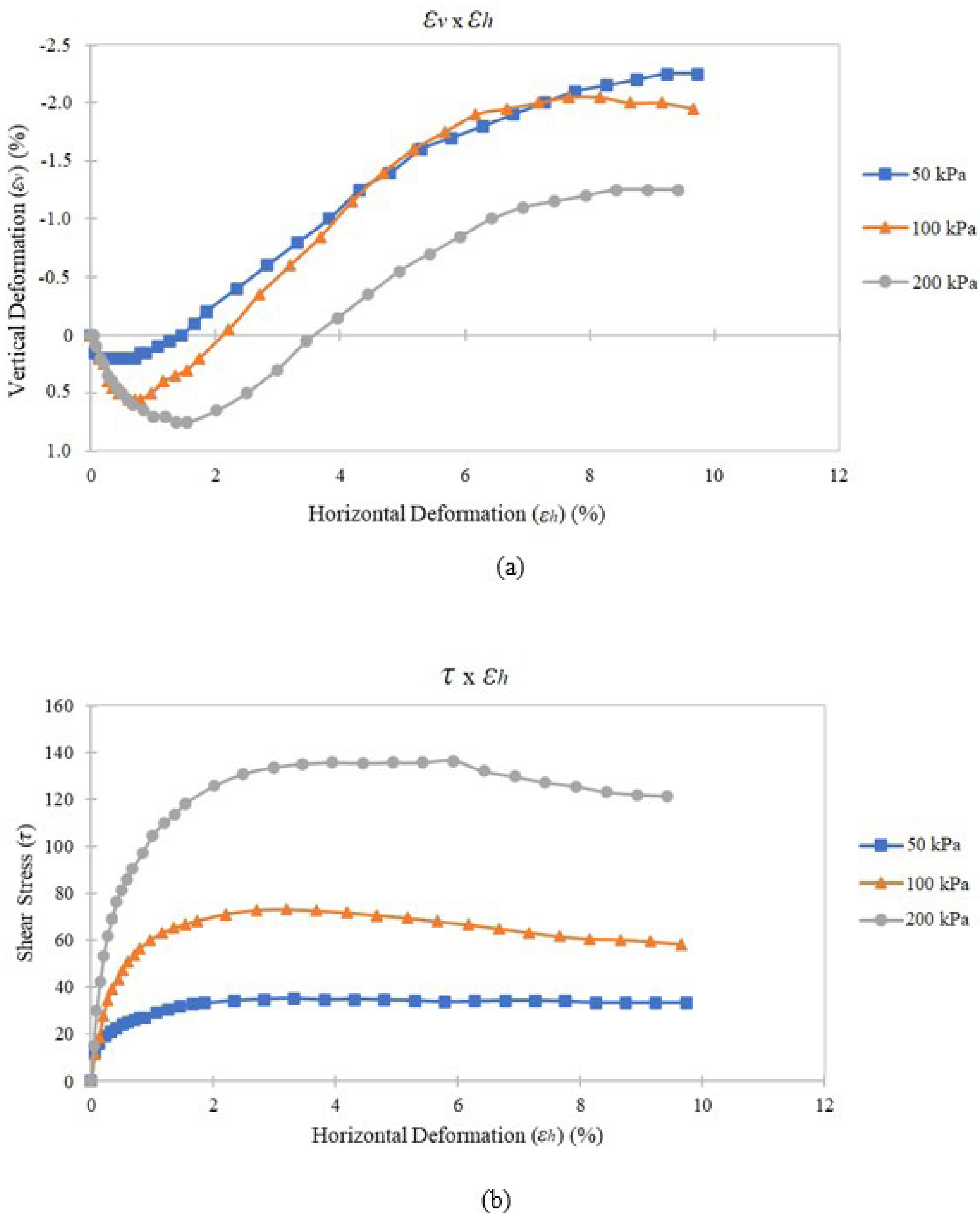


Figure 4. Example of data interpretation from a Direct Shear test: curves of (a) vertical deformation x horizontal deformation and (b) shear stress x horizontal deformation.

3.2 Slope stability

Figure 6 presents the result of the stability analysis proposed in the "Earthworks" course for a partially saturated heterogeneous slope, with the determination of the position of the potential circular failure surface and the indication of the global safety factor obtained by deterministic methods based on the limit equilibrium theory, such as those proposed by Bishop (1954), Spencer (1967), and Morgenstern & Price (1965). The fictitious heterogeneous slope was composed of two soil types and a bedrock foundation. The strength parameters provided for the materials are shown in the table presented in Figure 6, considering the Mohr-Coulomb failure criterion for soils 1 and 2 and infinite strength for the rocky layer. The analysis presented was performed in the *Slide2* software from Rocscience®.

The accomplishment of this activity was important for the practical demonstration of the application of the concepts studied, helping in the understanding and fixation of the contents. Thus, the students were able to verify that, despite the simplifications adopted in the simplified Bishop analysis method, it provides very accurate values of the factor of safety for circular failure surfaces, coinciding with the values obtained by the Spencer and Morgenstern & Price methods.

Figure 7 presents the results of the stability analysis proposed in the "Earthworks" course for one of the suggested geometries for the construction of a gabion retaining wall, with the determination of the circular potential failure surface and indication of the global factor of safety obtained by deterministic methods based on the limit equilibrium theory, such as those proposed by Bishop (1954), Spencer (1967), and Morgenstern & Price (1965). The material strength parameters follow the Mohr-Coulomb failure criterion and are presented in the same figure. For the gabion wall, high strength parameters were considered so that the failure surface would not cross the wall, and the global stability analysis corresponded to the soil-wall system. The analysis was performed using the *Slide2*® software. Additionally, it was found that for the evaluated situation, the factor of safety is satisfactory, being greater than 1.5.

Figure 8 shows the results of the percolation analysis proposed for a retaining wall with a vertical drainage system, performed using the *Slide2*®. In this analysis, it was possible to observe the flow network inside the soil mass, containing the water table surface, the flow lines, and the equipotential lines with the total loads presented in the legend, considering a situation where the soil mass is fully saturated.

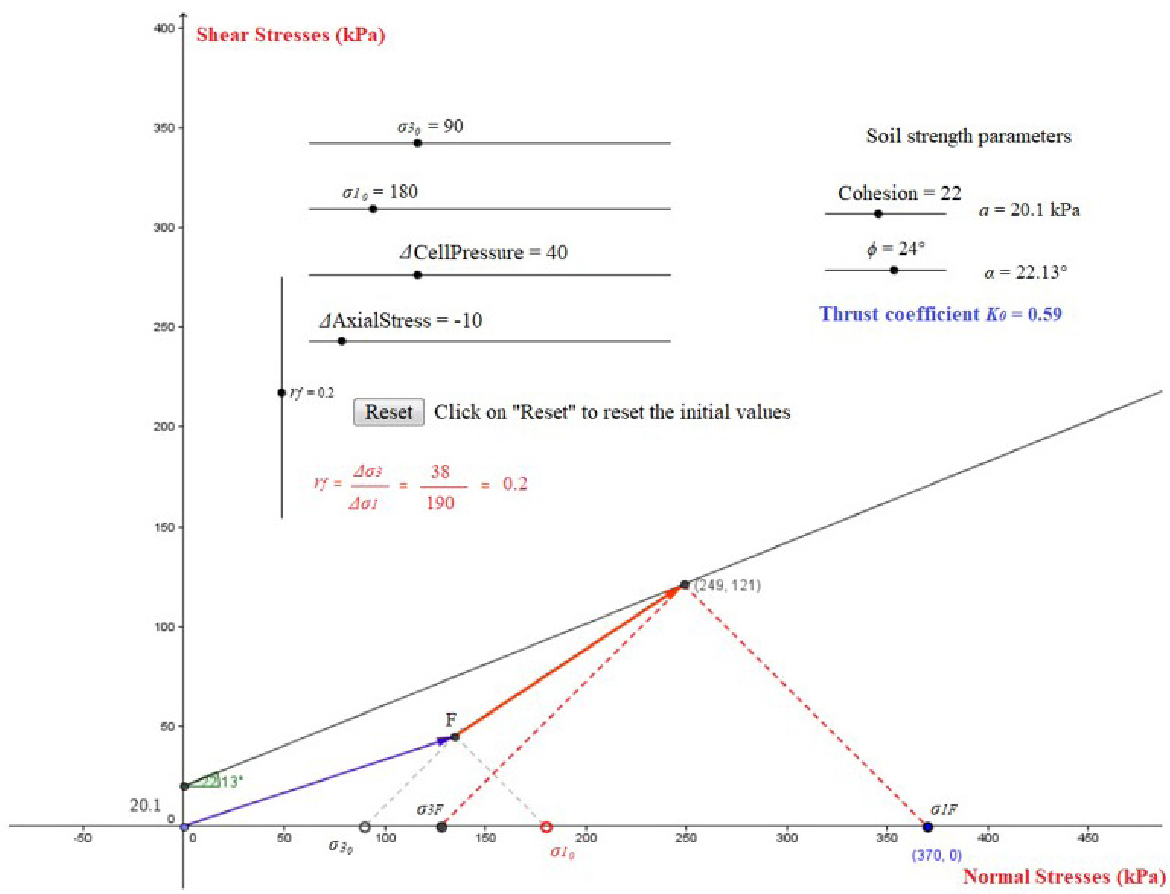


Figure 5. Application of soil stress trajectory. Adapted from Nalon et al. (2012).

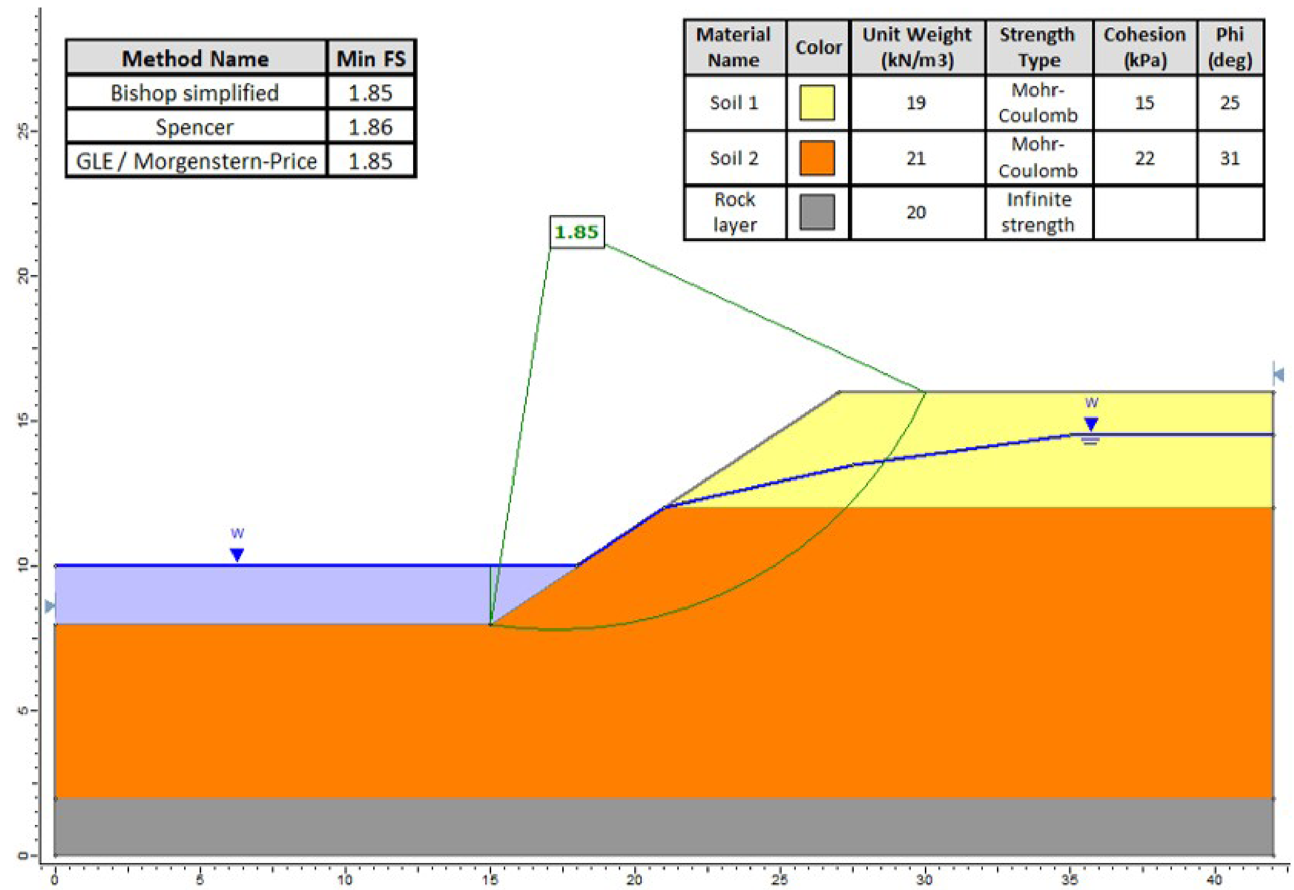


Figure 6. Stability analysis of a partially saturated heterogeneous slope.

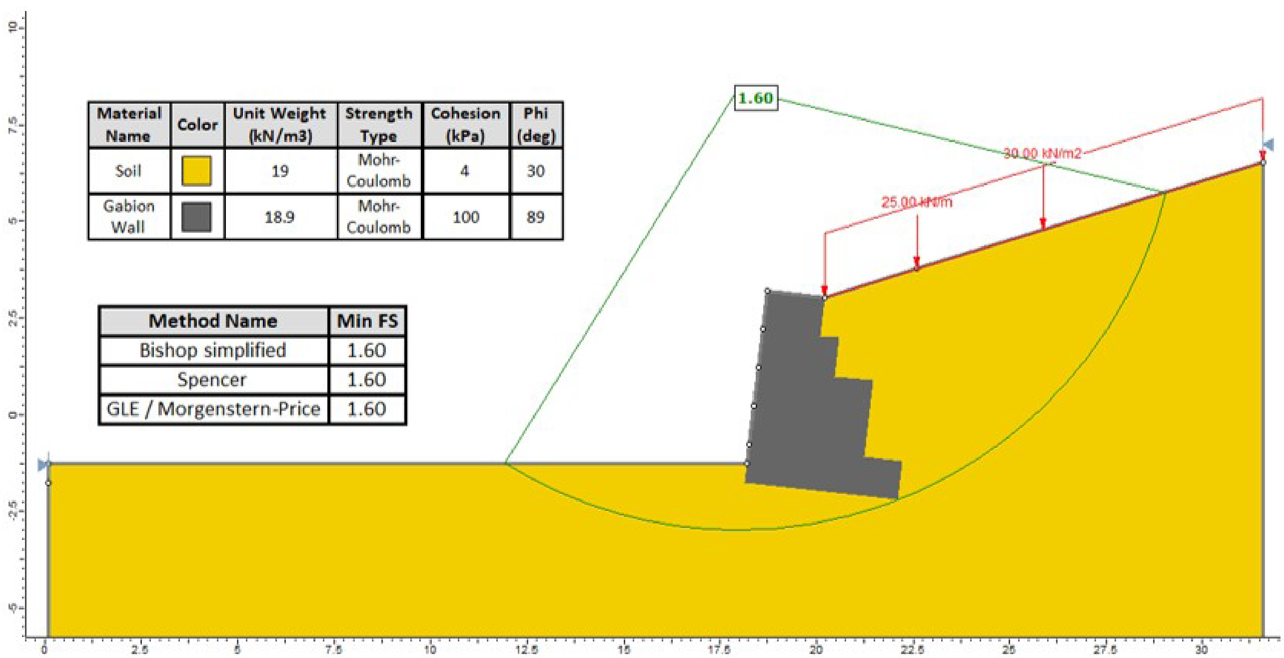


Figure 7. Stability analysis of a gabion retaining wall.

From the performance of these activities the students were able to visualize some practical applications of the concepts presented, as well as learn how to develop important evaluations in geotechnical projects. In addition, through the software, it was possible to simulate different scenarios of stability and percolation analysis, varying parameters such as wall geometry, material properties and overloads, in order to evaluate the performance of the structure under different conditions.

Figure 9a presents the stability analysis proposed in the discipline “Earth and Rockfill Dams”, carried out after the technical visit of the students to a dam site, indicating the factor of safety of circular potential failure surface obtained by the simplified Bishop method. Figure 9b presents the percolation analysis of the same dam, indicating equipotential surfaces. The stability and percolation analyses were performed considering a normal operating condition, with the reservoir at its operational level. The strength and permeability parameters of the materials that constitute the dam are presented in Figure 9. The analyses presented were carried out using the *Slide2*®. Furthermore, it was possible to verify that, for the evaluated situation, the global factor of safety is satisfactory, being greater than 1.5.

The completion of this work allowed the students to obtain a deeper understanding of the dam behavior in terms of strength and permeability, providing a clearer and broader understanding of the subject matter. This activity has contributed significantly to the development of essential skills for professional practice in the geotechnical engineering field, allowing for the acquisition of fundamental knowledge.

Therefore, through the use of digital tools in the disciplines “Earthworks” and “Earth Dams and Rockfill”, students were able to understand in a clearer, practical and more dynamic way the resolution of geotechnical problems, in addition to developing essential technical skills for the execution of projects in geotechnical engineering.

In this way, it is concluded that the use of these digital technologies greatly favors the teaching-learning process, allowing students to have access to actual tools commonly used in the industry. Furthermore, the use of these tools makes it possible to carry out accurate analyzes of the stability of slopes and other geotechnical structures, resulting in significant savings in time and resources.

3.3 Rock mass stability

For the proposed work in the “Engineering Geology” course, 74 discontinuities obtained through geological mapping could be grouped into three families (1m, 2m, and 3m), as shown in Figure 10. This plotting was constructed from discontinuities attitude data, using the Schmidt-Lambert network with equiarea projection, in the Rocscience® *Dips* software.

Figure 11 shows the attitudes of the three families of fractures and the two possible cutting planes (1 and 2) proposed for the construction of the highway. In addition, the lines of intersection between each family of fractures are presented, which were necessary information for carrying out the kinematic analyzes, in order to assess whether there could be any possibility of planar, wedge or toppling failure for the proposed geometry. Based on the analyses performed on the example in question, it was found that the two suggested slopes are equally unstable, and another slope with different attitudes should be proposed to meet the safety criteria against planar, wedge, and toppling failures.

Through the completion of this activity, the students had the opportunity to learn about the functioning of kinematic analysis software, in addition to visualizing in practice the concepts studied in the discipline, developing the sensitivity to evaluate how parameters such as plane direction, plane inclination, and discontinuity dip direction can influence the stability of a rock mass.

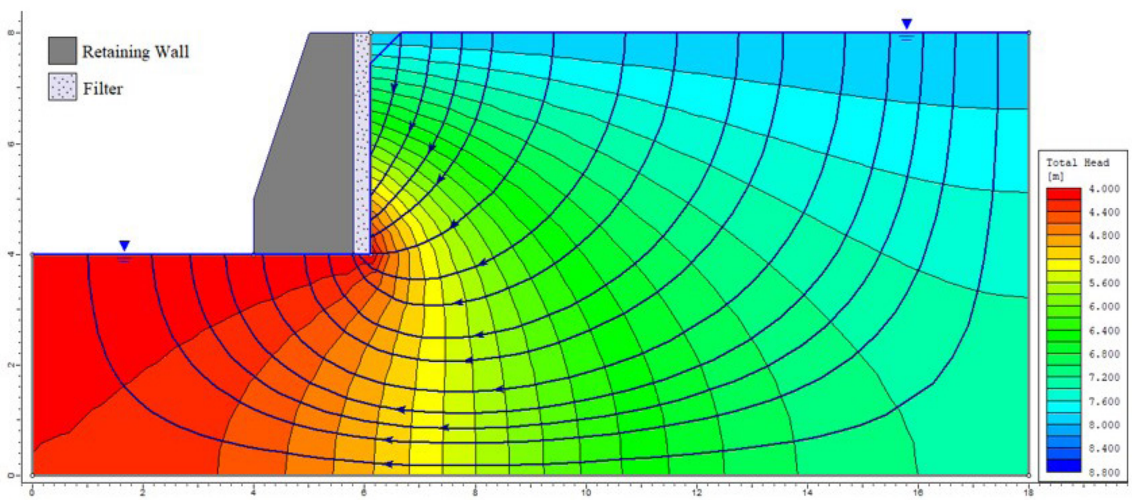


Figure 8. Percolation analysis in a soil massif, detailing the flow network.

In the “Introduction to Rock Mechanics” course several activities were proposed, but for illustrative purposes, Figure 12 presents an analysis of planar rupture stability in a fictitious rock mass, using the Limit Equilibrium Method through *RocPlane*®.

As observed in the image, the safety factor was not satisfactory, requiring the proposal of a solution to this problem. Thus, a possible alternative proposed by the students is presented in Figure 13, using rock bolts to increase the resistance of the rock mass, achieving an acceptable safety factor, greater than 1.5.

The use of these digital tools in the disciplines of “Engineering Geology” and ” Introduction to Rock Mechanics” provided students with a deeper understanding of the application of the studied contents, generating a practical experience closer to the challenges that can be found in some engineering projects.

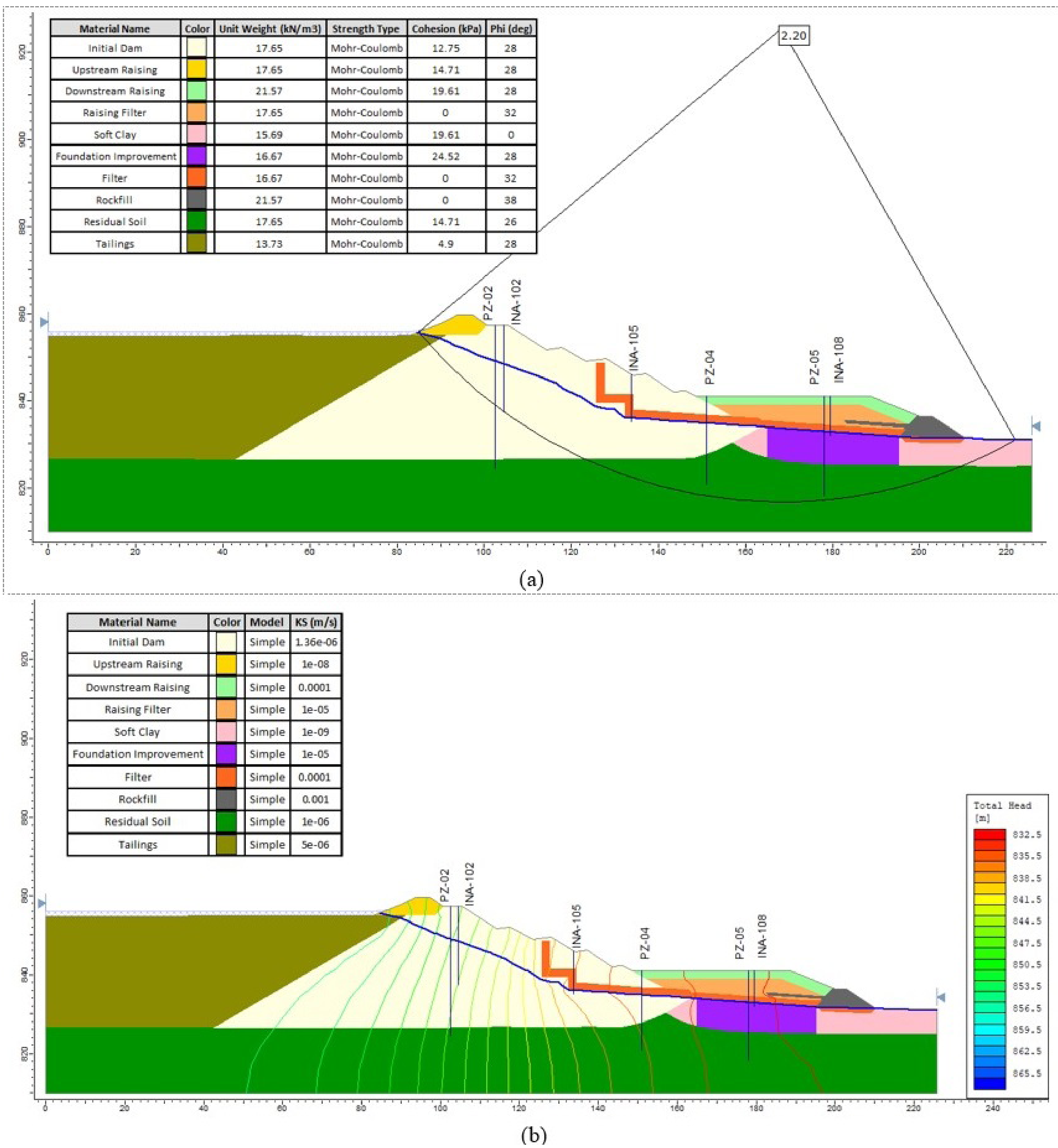


Figure 9. Analyzes of: (a) stability and (b) percolation of a dam.

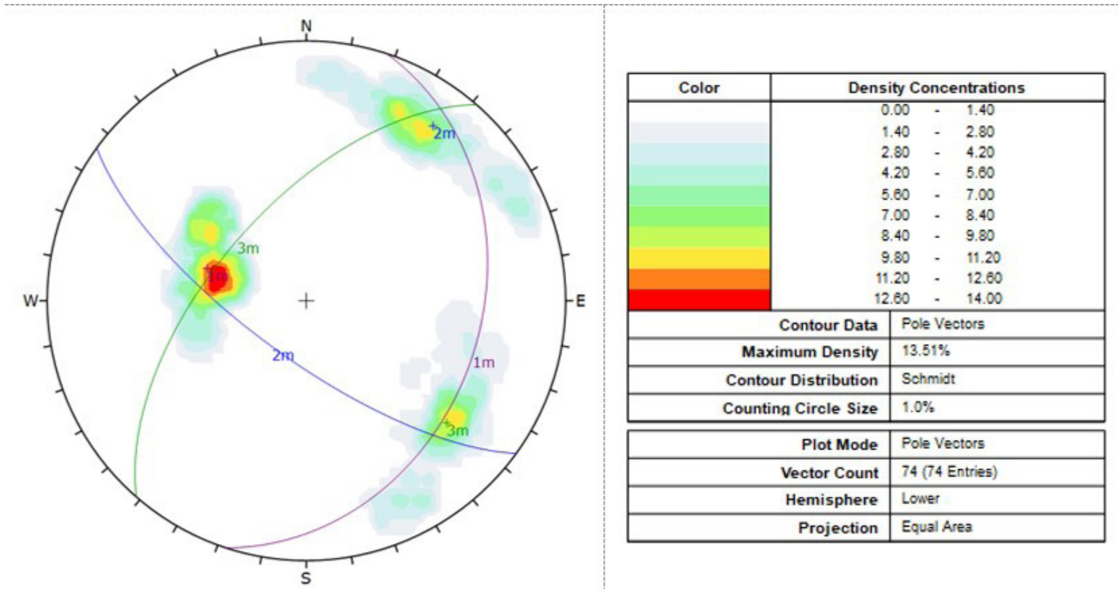
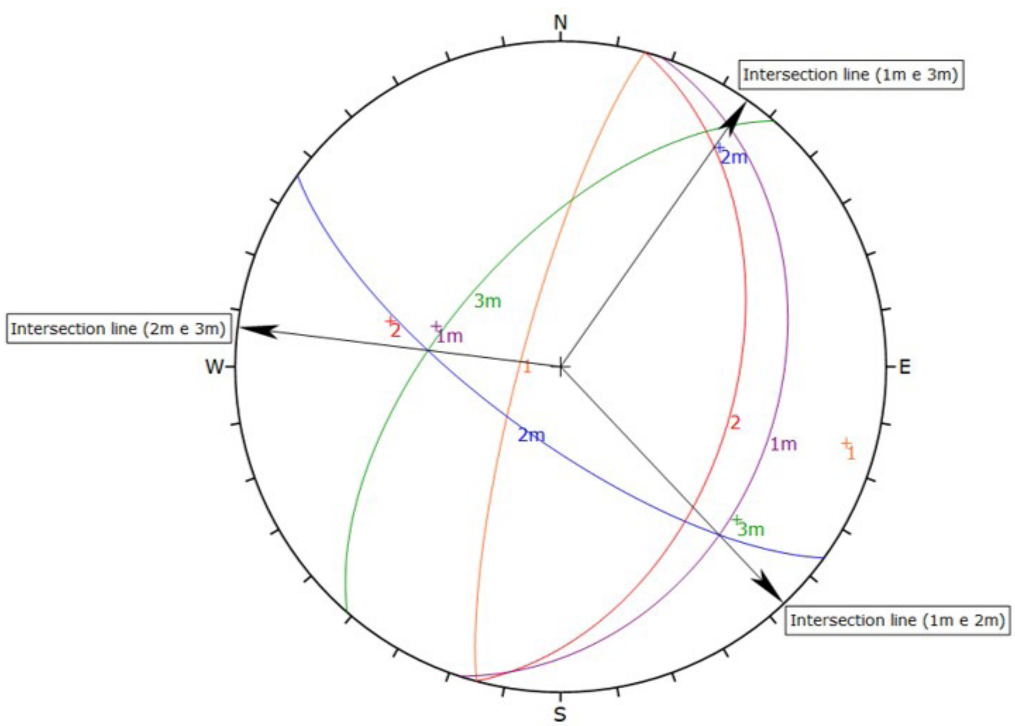


Figure 10. Representation of discontinuities grouped into families.



	Color	Dip	Dip Direction	Label
		User Planes		
1	■	80	285	
2	■	45	105	
		Mean Set Planes		
1m	■	33	108	
2m	■	72	216	
3m	■	61	311	

Figure 11. Plotting the attitudes of the cutting planes and fracture families.

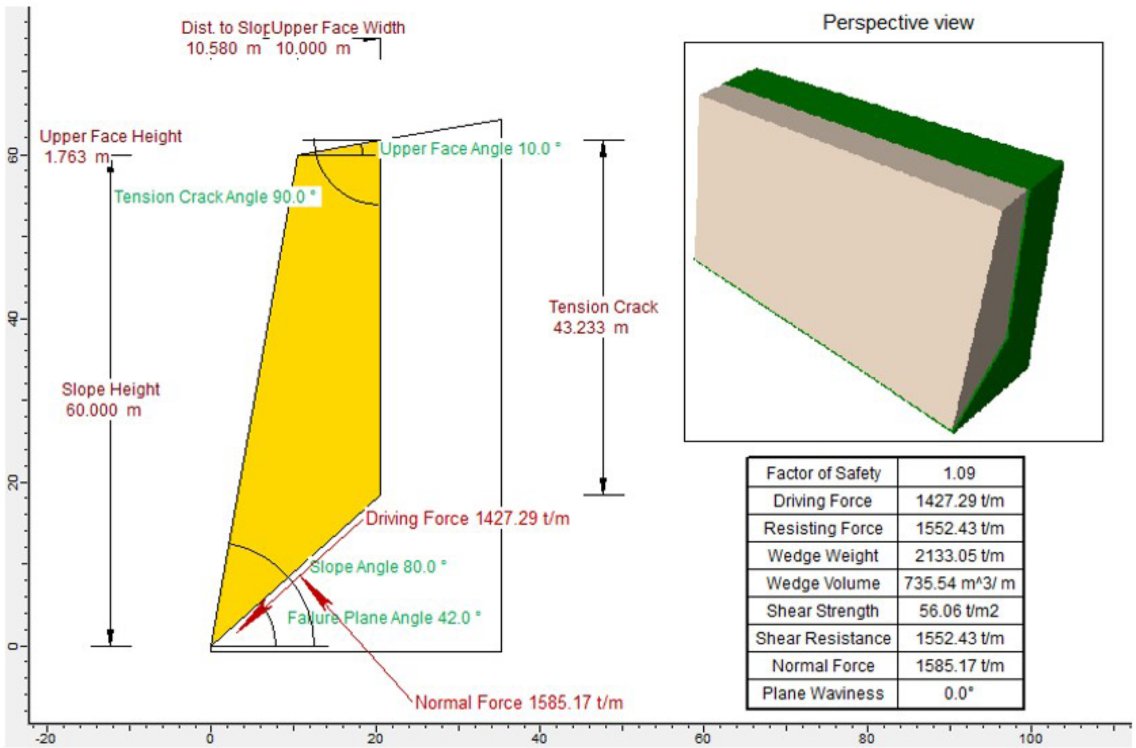


Figure 12. Planar rupture stability analysis in a rock mass.

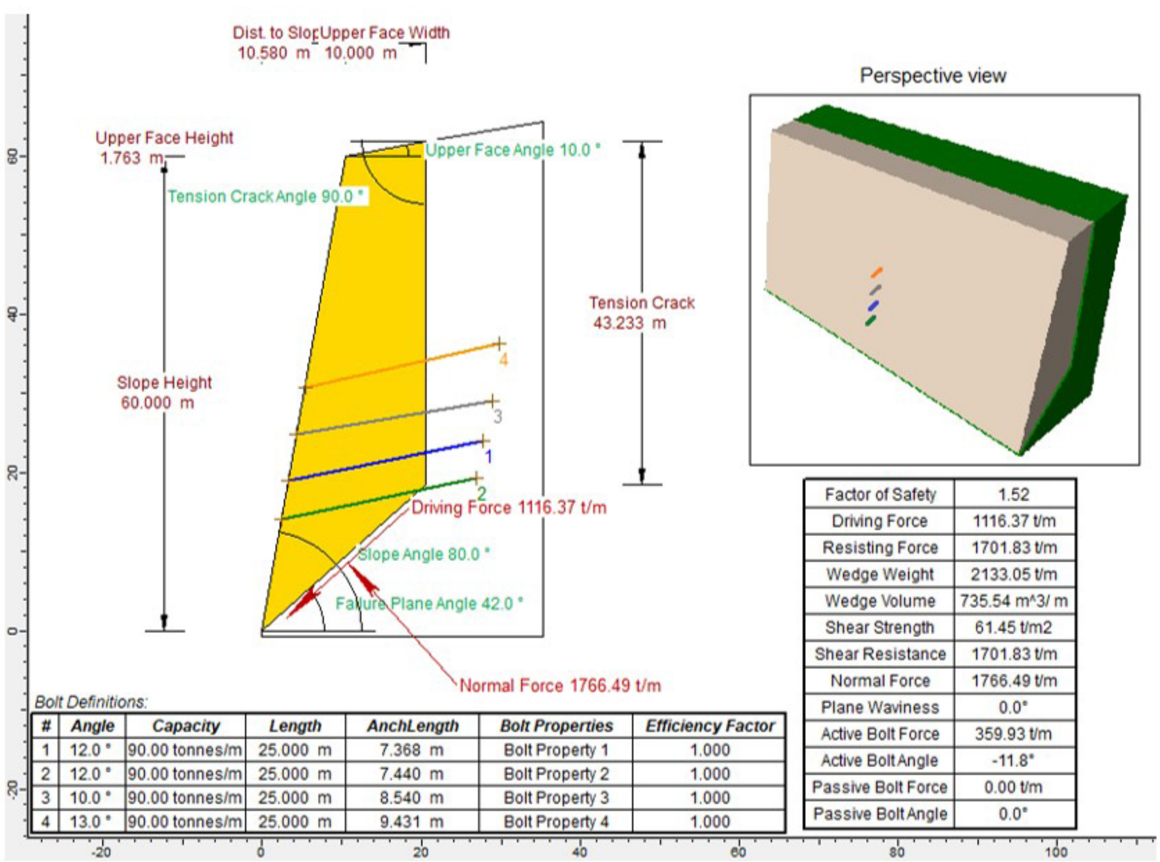


Figure 13. Planar rupture stability analysis in a rock mass with bolts.

Moreover, the use of these software programs allowed for three-dimensional visualization and rapid obtaining of results for the analyses and the optimization of the slopes design in an easy and real manner. Thus, the application of these technologies in the teaching of geotechnics can significantly contribute to the formation of more qualified and prepared professionals to face the challenges of the industry.

3.4 Feedback questionnaire

Based on the feedback questionnaire results, it was found that most students stated that the use of digital tools contributed to their learning in the Geotechnical Engineering disciplines. Among the responses recorded, students affirmed that this practice made the application of studied contents more visible, making the analyses and exercises more efficient, and contributed to the development of skills such as logical reasoning, critical thinking, and problem-solving.

When questioned about the software used, the students highlighted the help of *Excel* and *GeoGebra* in file preparation and analysis, as well as the use of analysis software such as *Slide2*, *Slope/W*, *Seep/W*, and *Dips*, which provide a practical and realistic application of the studied concepts, contributing to better preparation of students for the employment market.

Students were also asked about their perception of a hypothetical situation in which the courses did not use digital tools, and how this could affect their learning process. According to the students, the understanding of contents would be impaired by the difficulty in visualizing and analyzing the information, requiring much more time to understand the problem, and to carry out the activities and facing greater challenges to the treatment of data from laboratory tests.

In addition, the subject teachers and the course coordination stated that they have been monitoring the professional performance of graduates. It has been observed that the skills resulting from the use of these computational tools have been a distinctive factor in the hiring and performance of these professionals by engineering project companies in the fields of Geotechnics and Structures.

Furthermore, as suggestions, some students pointed out the importance of spreading the use of software in other Geotechnical Engineering disciplines, in order to further expand the benefits of their use in the learning process.

4. Conclusion

Based on the topics covered in this paper, it was possible to conclude that the use of softwares and other digital tools in the teaching-learning process in geotechnical engineering is a very important and efficient strategy, promoting active and dynamic learning and a deeper understanding of the theoretical and practical concepts studied.

The use of the “Soil Physical Indexes” application, used in the “Soil Mechanics I” course, allowed students to review and exercise the knowledge learned during the classes. In addition, the use of some tools on Excel for the “Soil Mechanics II” discipline was very important for interpreting results of direct shear tests, while *GeoGebra* contributed to better visualization of the Mohr-Coulomb diagram and for determining the soil shear strength. The use of these tools made it possible to demonstrate the influence of changing values in certain equations in a more effective way, saving the time that would be required with manual calculations.

In the disciplines “Earthworks” and “Earth and Rockfill Dams”, the use of slope stability software enabled the learning of stability and percolation analysis in slopes, earthworks with containment structures, and earth and rockfill dams. These technical skills developed are essential for conducting real projects in geotechnical engineering and are widely used in the market, providing better preparation for students to work in the industry.

The use of kinematic and rock mass stability analysis software in the courses “Engineering Geology” and “Introduction to Rock Mechanics” allowed for the evaluation of the orientation of fractures present in the analyzed rock masses, with three-dimensional visualization of the analyses and obtaining results more efficiently. Additionally, the proposed activities enabled students to suggest possible engineering solutions for cases where the safety factor was not satisfactory, depicting a very common situation in the practice of geotechnical engineering.

The results obtained through the feedback questionnaire applied to the students indicated that the use of digital tools in Geotechnical education significantly contributed to the students’ learning process. According to the collected responses, the software used helped to make the application of the studied concepts more visible and improved the students’ skills. Furthermore, the students pointed out that the lack of these tools could impair their understanding of the contents, increasing the time required to perform the activities. As a suggestion, some students highlighted the importance of spreading the use of software to other disciplines in the area of Geotechnics.

Declaration of interest

The authors have no conflicts of interest to declare. All co-authors have observed and affirmed the contents of the paper and there is no financial interest to report.

Authors’ contributions

Carolina Crissafe dos Santos Lemos: conceptualization, data curation, visualization, writing – original draft. Luiz Otávio Fontes Dias: conceptualization, data curation, visualization, writing – original draft. Paulo Sérgio de Almeida Barbosa: software, supervision, validation, writing – review & editing. Eduardo Antonio Gomes Marques: supervision, validation, writing – review & editing. Roberto Lopes Ferraz: supervision, validation, writing – review & editing. Gustavo Henrique Nalon: methodology, software.

Data availability

The datasets generated analyzed in the course of the current study are available from the corresponding author upon request.

List of symbols and abbreviations

a	Rupture envelope intercept
e	Void ratio
n	Porosity
r_f	Loading ratio
w	Moisture content
INA	Water level indicator
K	Thrust coefficient
P_s	Dry sample weight
PZ	Piezometer
UFV	Federal University of Viçosa
V	Total sample volume
α	Rupture envelope inclination angle
Δ	Variation
ε_h	Horizontal deformation
ε_v	Vertical deformation
ϕ	Angle of friction
γ	Natural specific weight
γ_d	Dry apparent specific weight
γ_s	Specific weight of grains
σ_1	Major principal stress
σ_3	Minor principal stress
τ	Shear stress

References

Bishop, A.W. (1954). The use of the slip circle in the stability analysis of earth slopes. *Geotechnique*, 5(1), 7-17.

Haleem, A., Javaid, M., Qadri, M.A., & Suman, R. (2022). Understanding the role of digital technologies in education: a review. *Sustainable Operations and Computers*, 3, 275-285. http://dx.doi.org/10.1016/j.susoc.2022.05.004.

Marques, E.A.G., & Vargas Júnior, E.A. (2022). *Mecânica das rochas* (184 p.). São Paulo: Oficina de Textos (in Portuguese).

Morgenstern, N.R., & Price, V.E. (1965). The analysis of the stability of general slip surfaces. *Geotechnique*, 15(1), 79-93.

Nalon, G.H., Sabioni, B.C., Nascimento, W.D., & Barbosa, P.S.A. (2012). O uso do Geogebra no ensino de mecânica dos solos. In *XL Congresso Brasileiro de Educação em Engenharia*, Belém. Retrieved in May 12, 2023, from https://www.researchgate.net/publication/316610611_O_uso_do_GeoGebra_no_ensino_de_Mecanica_dos_Solos (in Portuguese).

Nalon, G.H., Aredes, A.C.N.B., Bizão, A.H.N., Nascimento, W.D., & Barbosa, P.S.A. (2013). Implementação de um software educacional interativo sobre índices físicos dos solos. In *XLI Congresso Brasileiro de Educação em Engenharia*, Gramado. Retrieved in May 12, 2023, from https://turing.pro.br/anais/COBENGE-2013/pdf/117089_1.pdf (in Portuguese).

Spencer, E.A. (1967). A method of analysis of the stability of embankments assuming parallel inter-slice forces. *Geotechnique*, 17(1), 11-26.

United Nations. (2023). *Sustainable development goals*. Retrieved in May 1, 2023, from https://www.un.org/sustainabledevelopment/education/