

Original Research Article

MOVEMENT OF WATER ON THE SOIL: TEACHING BY THE USE OF PHYSICAL MODELS

ABSTRACT

Dams, embankments, roads, and other structures are subject to stress changes due to pore pressure, which can lead to instability and even failure. This paper aims to present the practical activities developed in the Soil Mechanics Department of the Civil Engineering Course of the State University of Minas Gerais - João Monlevade, Brazil, which dealt with the movement of water in soil structures and discussed the design and stability aspects of these, to develop the student's protagonism through direct involvement in the design and execution of the physical model. This topic is crucial for geotechnical engineering and even more so for the region where João Monlevade is located, as several iron mining companies use tailings dams and earth structures. Therefore, knowledge of the laws and conditions governing the movement of water in these structures is necessary for the students who will design them in the future. The development of the activities was preceded by theoretical discussions on aspects such as the laws governing the flow of water in the soil, the types and characterization of soil and tailings, and the influence of the safety factor. These activities were developed in 2018, 2019, 2022 and 2023. As a result, a learning gain was achieved because the models were developed on a small scale by the students, who personally checked the variation of the parameters of the materials and water in the experiments.

Keywords: physical models, engineering education, dams, poro pressure

1. INTRODUCTION

Soil is a heterogeneous medium with pores through which water can flow. Understanding how water moves through earth structures is fundamental to these projects as it affects the stress state and consequently the geotechnical behavior and stability of the structures, throughout the life of the project and when it is finally decommissioned.

The concepts of water movement in soils have generally been studied by geologists, civil engineers and mining engineers in the discipline of soil mechanics. However, it's not always easy to understand and visualize, especially when there is no direct contact with structures. The use of physical models in the teaching of soil mechanics has proven to be an excellent strategy for developing technical skills and for civil engineering students to fully understand processes when they design and build these models themselves.

Although physical models are very useful tools for learning geoscience and hydrogeology, there are few reports on their use in Brazil.

This paper deals with the use of physical models to understand water movement in different types of soils and their application to the stability of slopes and earth dams. The objective is to help students visualize and understand the processes that govern water movement in the soil. The proposed activity has been applied in the Civil Engineering course of the Faculty of Engineering of the University of Minas Gerais (UEMG), to familiarize future engineers with the design of earth dams and embankments and the concepts of permeability, hydraulic head, velocity and flow in porous media, as well as to integrate theoretical knowledge with practice through the development of projects.

Therefore, this paper aims to discuss the importance of teaching about water in soil and its influence on engineering structures through practical activities.

1.1 The use of physical models in Engineering and Geosciences

The physical or virtual models for teaching Engineering and Geosciences has important functions in engineering research. Physical models are of great importance in engineering projects because they allow studying phenomena on a reduced scale that are of interest to the projects to be developed, including in an educational environment such as the teaching the formation of structures in Geology [3] and applications in Hydrology and Soil Mechanics [6] like the works involving the use of physical and/or virtual models, it is possible to quote the ones like use of similar models [1] [2] [4], models for simulations of soil hydraulic phenomena [26] [27], development of didactic devices in support of discipline Geotechnics [7],[8][9][27], construction of low cost physical model for percolation in soil [24], physical models for class-room teaching in hydrology [12] [22], sand box experiments [16],[25] development of software to simulate flow in soil [11][17][18], review of practices in classroom [11], teaching groundwater flow process [12][13], use of prototype for study of sandy soils [20], development of exercises with soil flow [5] among others.

According to [19] [28] the science requires, not only knowledge, but practice for your development. Thus, the engagement of the students in practices of science helps them understand how scientific knowledge is constructed and your participation gives on investigation and construction of models allow them to understand and facing future challenges. Some works refer to the use of physical and even virtual models for Hydrology and Soil Mechanics that may be applied for teaching and learning Hydrogeology.

The innovation in the traditional teaching of Geosciences – including Hydrogeology – is necessary due to rapid development in the last years, of the 2D and 3D software's that modeling the stability of civil structures with water flow and your effects on stability, safety factor and others parameters, requiring the knowledge of the environment characteristics for a correct evaluation of sceneries of soil/water contamination, stability of earth dam, tailing dam, water level variation and its effects, for example.

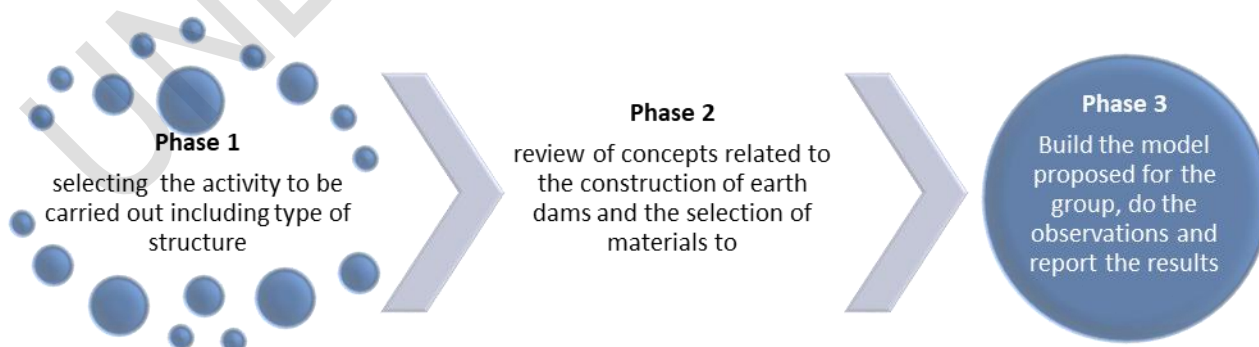
Despite this, the use of didactic physical models for understanding the parameters that compound this modelling like Darcy's Law, hydraulic conductivity, porosity, storage, heterogeneity of the environment is not very common in Brazil, since there are few articles and reports of its usage. In many Brazilian universities there is low availability of equipment for exclusively didactic ends, before their high acquisition value and, also, problems with physical space, proposing, as a solution, projecting and confectioning equipment with smaller dimensions with didactic end, inside the universities, in order to help students understand physical phenomena [15].

The state of Minas Gerais was the scene of two major environmental and engineering disasters in the last decade: the break dams of Mariana (2015) and Brumadinho (2019) [14], [21][23] that caused deep impact in society and understanding the operation of this type of structure is fundamental for engineering. The soils and tailings are heterogeneous materials and understanding their geotechnical properties is fundamental for the safety of these structures.

In no way was it intended to replace the complex technical analyses involved in the construction and operation of these dams, but rather to provide the student to explore solutions required translating interdisciplinary knowledge, using physical models developed with simple equipment consisting of wooden and glass boxes, built at the university itself, or acrylic boxes (already available in the Soils Laboratory), as well as using soils and tailings available in the region. The aim was to develop activities that would allow students to check the construction processes of dams on a reduced scale and to check the movement of water in the soil combining your knowledge and creativity for this [10].

2. METHODOLOGY

figure 1 : This research is qualitative and was developed based in steps illustrated in



2.1 Description of activities performed in each phase

Phase 1:

1. Select an engineering practice to analyze: Building of earth dam and tailing dam
2. Identify the academic objectives of the engineering practice.
3. Identify and prioritize the key elements and resources of the practice.
4. Identify the Assessment of Learning

Phase 2

1. Review of concepts associated with the design and construction of dams such as slope stability, flow, drainage structures, permeability, porosity, hydraulic conductivity, Darcy's law, kinds of soils, stress acting in the soil (stress vertical, pore pressure, effective stress) among others.

Phase 3- Building the physical model in the course of Soil Mechanics of Civil Engineering for verifying the water movement in earth dam and your consequences.

The proposal to analyze the water movement in the soil and its influence in earth dams and the development of the line flow through earth dams built by students, was developed by the author in the Soil Mechanics II class of Civil Engineering of UEMG (Minas Gerais State University) in Campus João Monlevade.

According to [19], in an experiment of investigative nature, the experiment is carried out to start the lesson, which has its theoretical basis in the experiment carried out, where knowledge is built together between teacher and students, allowing discussion of theories and critical thinking. In this way, despite the guidelines previously presented, it is possible to address issues related to the project under development, as well as to discuss doubts.

Before the classes, a script was presented to be followed in the preparation of the project, with dimensions, materials, necessary characterizations, observations to be made, among others. These activities included:

- a) Determine the granulometric curve of the soils to be used in the boxes.
- b) Calculation of the volume of each material to be used in the construction.
- c) Preliminary analysis with dimensioning of slopes and filters.
- d) Execution of the earth embankment and embankment construction works:
 - d.1. Verification of the stability of the structure considering: a) dry ground and two situations: reservoir completely flooded and partially flooded.
 - d.2. Verification of the stability of the structure during the filling of the reservoir and during the formation of a linear flow (flow net).

Figure 2 A through C shows the structure of some of these activities.



Figure 2- Construction of earth dam by students- A- homogeneous earth dam, B- earth dam with vertical drainage, C- tailing dam

Considering that the visualization is an important component in the learning process and that it allows a better understanding of the phenomena, the objective of the activity was to use a prototype to simulate, in a practical class in the

laboratory, the water movement in the earth dam, since, although widely studied, this is a phenomenon with difficult visualization and understanding in the classroom and has a great importance for civil engineering.

The earth dams were built in a glass box, of low cost, with soil collected by the students who made their physical characterization of the test of granulometry and visual-tactile description.

The proposal was to build at least two earth dams in a reduced model, with different types of soil, classified as silty sand and sandy clay, one without a drainage filter and the other with a filter, to verify the variation of the water level inside the structure in both situations.

To facilitate the visualization of the flow lines, colored ink (magenta and orange) was used in the water.

The variations observed in the behavior of the earthen dam were noted by the students and described in reports, including the rate of percolation of the water in dry soil and after saturation.

Students were instructed to observe and report on the formation of flow lines as the experiment progressed, and at the end of the experiment, conditions of rupture of the structure by piping and overflow were also simulated. In addition, during the experiments, the concepts related to the filters in the dams were discussed, such as their importance in water level control and methods for their construction.

3. RESULTS AND DISCUSSION

The teaching and learning process, which is focused on the use of teaching that stimulates the initiative of students and aims to contribute to a broader vision of knowledge (which provides the necessary knowledge for solving problems) and not just a fragmented vision.

Considering that the research is qualitative, the results have been evaluated in terms of student learning and this proved to have been very positive, because besides verifying the movement of water's in the dams, the neutral pressure's actions in soil structures, principles of design of these structures, the students have participated of collecting and characterizing the soils and were able to notice the importance of knowing the characteristics of the materials (soil and tailings) with which they are working.

In 2022 and 2023, students were asked to evaluate the activity in terms of learning and the resources used answering two questions: 1) Was the script presented and the project developed important in expanding your knowledge? 2) Were the resources used sufficient? From 24 students there were a total of 13 responses summarized in Figure 3.

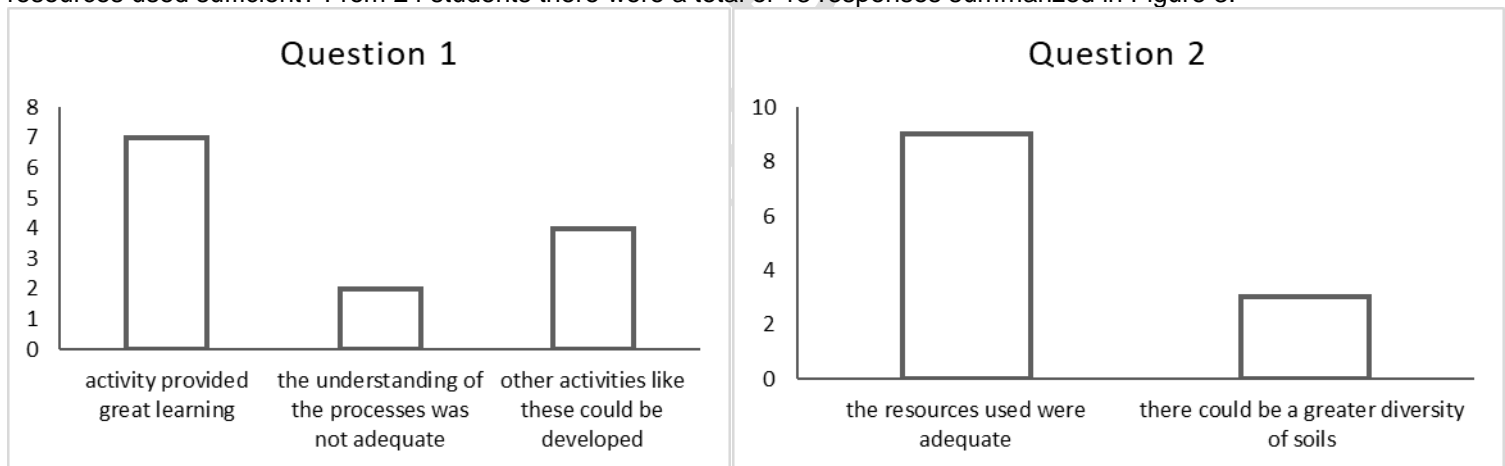


Figure 3- Student evaluation on 2022 e 2023

The activities aroused the interest and curiosity of the students, since there are numerous dams in the region, including tailings dams, where the University is located (Itabira micro-region, MG, Brazil).

The results were considered positive by the students, as the visualization of the flow networks allowed them to understand the phenomenon of water movement in earth dams, a structure present in many cities of the region, whose construction and operation require great knowledge to avoid serious damage.

Despite the relative simplicity of the experiments carried out, due to the economic difficulties of constructing more elaborate models, their implementation was well received by the students, as it not only motivates them, but also provides a playful teaching alternative.

It was possible to verify that the experiments can be improved by using stronger tinting dyes to facilitate the visualization of the flow, as well as by constructing larger boxes or new prototypes that allow the study of parameters already studied, as well as the verification of hydraulic loading, pollutant migration (simulated with tinted water), among others, in prototypes as proposed, for example, by [9] and [22]

The fact that the students carried out the physical characterization of the materials used, decided on the geometry of the dam, how it would be executed, verified in the laboratory any difficulties that would be encountered in the field, and observed the results of their work was a challenge that certainly resulted in significant learning...

4. CONCLUSION

In the work conducted, it has been possible to test the hypothesis that students from the Civil Engineering course know better the water behavior in different soils and how the subterranean water flow taxes are, connecting physical and numerical models.

The experimentation together with the theoretical knowledge has allowed the students to connect the processes that they see in the laboratories with the results of numerical models, and thus the learning process has been enhanced by a better understanding of the magnitude and importance of the properties and parameters that control the water flow in the soil.

The extension of the parameters to be analyzed, as well as the development of prototypes with water drainage and hydraulic loading verification mechanisms, will allow a deeper knowledge of hydrodynamics and flow than in the previous step, since there have been positive results in their application and the students' suggestions will be incorporated in future activities.

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