Experimental, Numerical and Virtual Tools in Civil Engineering

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Abstract—**Three sets of teaching tools developed for Civil Engineering students are presented in this paper. The first is a didactic test frame for structural mechanics and its virtual replica. The second is an outfit for small scale seepage studies. The third is a set of portable devices for visual demonstration of several phenomena of interest for introductory soil mechanics classes.**

Index Terms—**Engineering education, soil and structural mechanics, teaching tools, virtual and remote labs.**

I. INTRODUCTION

Experimental activity develops a strong connection between theory and reality by the observation of concepts and principles at work. This is instrumental for building a mental model through the construction of meaning during the learning by doing process [1], and for achieving deeper knowledge together with the ability to solve practical problems [2].

Experimental activity is fundamental in many teaching fields and especially in the engineering area. It gives a priceless contribution to the Bologna student centred concept, by fostering student autonomy in the process of acquisition of new skills, competences and knowledge [3].

The evolution of the World Wide Web and the new tools offered by the information and communication technologies during the last decade have opened new horizons to the teaching/learning process, particularly within the engineering fields [4].

During the past five years and in cooperation with a group of students and teachers, the author has been engaged in the development of various teaching setups for structural and soil mechanics which provide experimental visualization and measurement of relevant physical quantities that may then be compared with theoretical values and/or those obtained by numerical modelling by the finite element method.

This paper presents three sets of teaching tools: one experimental setup for structural mechanics that has been complemented by its virtual counterpart; one apparatus developed for small scale study of groundwater flow that may be remotely accessed by means of an IP network camera; and, finally, a set of portable devices for demonstration of soil mechanics related phenomena.

The design and development process of the teaching tools was a rich multidisciplinary experience that required a very wide range of skills and sound engineering judgement. Student feedback has been very positive regarding the pedagogical value of the tools.

II. EXPERIMENTAL AND VIRTUAL TOOL FOR STRUCTURAL MECHANICS

Many approaches have been proposed in order to improve the teaching/learning of structural mechanics based, for example, on e-learning and software developed applications, multimedia applications or mathematical models [5-7]. But the observation and testing of structural models still play a key role in providing a direct contact with the principal concepts and methods of structural analysis, whereby the theoretical background is combined with the visualization of the physical phenomena.

That is why a didactic test frame has been designed and built at Faculdade de Engenharia da Universidade do Porto (FEUP) (Fig. 1), where it is used both for practical laboratory assignments and for supporting lecture presentations [8]. Voice and video communication facilities were added, using Skype® and an IP network camera, connecting in a very convenient and effective way the lecture theatre to the structural laboratory.

At the end of the semester four questions were posed to the students: (i) How much did the test equipment contribute to a better appreciation of the underlying theory? (ii) To what extent did it provide a deeper understanding of structural concepts? (iii) Did it improve the ability to solve force method and influence line problems? (iv) Would you like to have a virtual replica of the experimental setup on your laptop?

Fig. 2 presents the questionnaire results on a scale from 1 (Awful) to 7 (Excellent). Student opinion has been very positive and given the general demand for a virtual replica such development has been undertaken, the end result being SoftBeam [9, 10], a virtual reality application whose primary goal is to provide students with easy access to the main features of the experimental setup in order to facilitate knowledge integration with the perception of demonstrations ("seeing is believing"), to promote "virtual practice" and its feedback, to observe details, to stimulate cooperative activity, to learn sequentially and to synthesize knowledge.

Figure 1. Experimental structural setup (left) and virtual replica

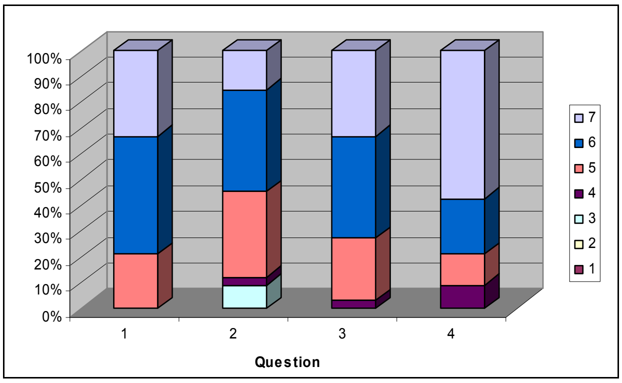

Figure 2. Student feedback on the use of the structural setup

SoftBeam reproduces the test frame geometry and operation in a very realistic way, with a careful choice of textures and lighting that enhance the sense of presence (Fig. 1).

It combines a precise structural analysis module with a friendly user interface developed in OpenGL, featuring zoom, pan and rotation and animation facilities. SoftBeam is a teaching/learning tool that successfully circumvents the limitations associated with the availability of the real test frame.

III. SETUP FOR SMALL SCALE SEEPAGE STUDIES

Seepage or groundwater flow is one of the topics typically covered in introductory Soil Mechanics courses for Civil Engineering.

Experience has shown that students have some difficulty in mastering the basic concepts, mostly because of their lack of feeling for the underlying physics.

The reason for this may be related to the fact that the development and training of student sensitivity is primarily oriented for mechanical and structural problems in courses like Mechanics, Strength of Materials, Structural Analysis and Concrete Structures.

This mechanical emphasis is probably a familiar scenario in most Civil Engineering schools.

In order to help alleviate student difficulties with seepage the availability of an experimental didactic apparatus was considered of paramount importance, particularly for providing a clear visualization of the phenomena involved.

The development of one laboratory equipment for small scale study of seepage problems has therefore been proposed as the theme of one Master thesis [11, 12] (Fig. 3).

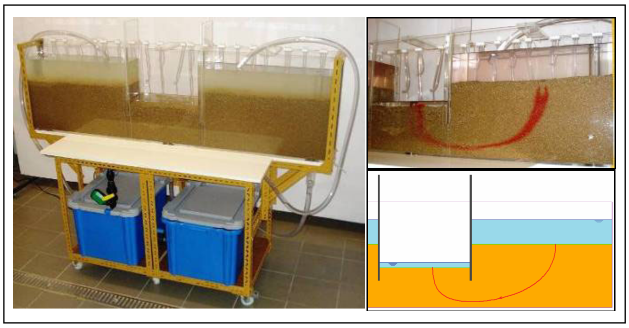

Figure 3. Small scale study of seepage around a cofferdam

The experimental apparatus has three main components: the main acrylic tank (2000 mm long, 585 mm high and 200 mm wide), the support structure and the hydraulic closed circuit.

Fig. 3 shows on the left a global view of the equipment during the performance of a small scale study of groundwater flow around a cofferdam. One flow line has been visualized by injection of a dye and the two images on the right side of Fig. 3 show that good agreement exists between this experimental result and the one provided by numerical modelling with finite elements.

In Fig. 4 comparison is established for total hydraulic head values obtained with those two alternative approaches. A new fibre optic sensing element for measuring pore water pressure is under development with good preliminary results.

The seepage apparatus has been used for a detailed small scale study of flow in earth dams [13, 14].

In homogeneous dams the phreatic surface intersects the downstream face and various types of drain may be employed in order to prevent such occurrence. Drainage blankets, toe drains and chimney drains are currently used to intercept seepage water before it reaches the downstream slope and may be used in conjunction with an impervious clay core (Fig. 5).

The operation of these types of drain is illustrated in Fig. 6, where flow lines are highlighted by dye injection.

The activity of the experimental setup can be viewed from the lecture theatre via an IP network camera (Fig. 7). Such provision enhances the pedagogic value of this teaching tool and increases its availability in a very convenient way.

The combination of the small scale experiments with their finite element simulation has the objective of establishing a concrete connection between the physical reality and its computational modelling whose intended result is to provide the conditions for a deeper learning experience.

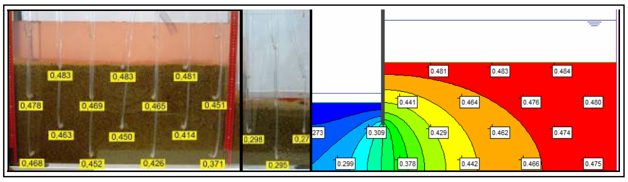

Figure 4. Small scale study of seepage around a cofferdam

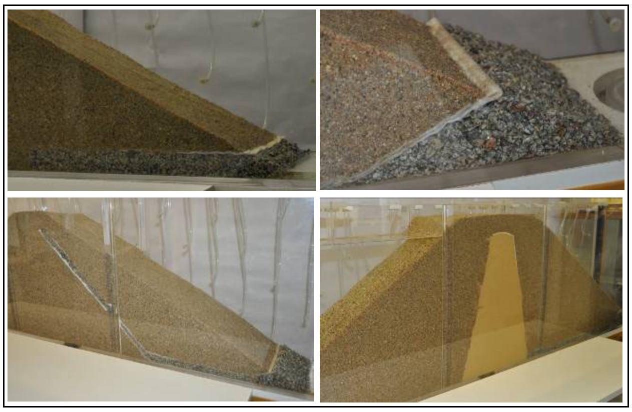

Figure 5. Drainage blanket, toe drain, clay core and chimney drain (clockwise from top left)

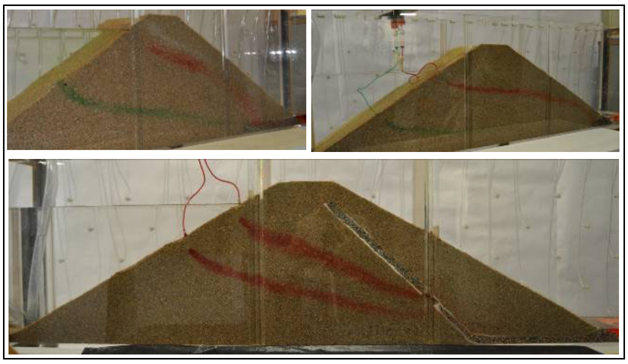

Figure 6. Flow lines in a dam with drainage blanket, toe drain and chimney drain (clockwise from top left)

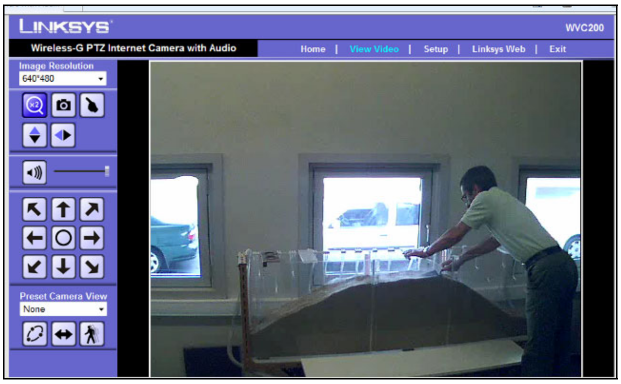

Figure 7. Graphical user interface of the IP network camera as viewed from the lecture theatre

IV. PORTABLE TEACHING TOOLS FOR SOIL MECHANICS

A number of small scale, portable and inexpensive experimental setups have been developed with the purpose of making available to Civil Engineering students very simple and suggestive teaching tools for demonstrating some Soil Mechanics phenomena in order to facilitate the learning of fundamental principles [15, 16].

The following three topics have been addressed: i) lateral soil pressure on a retaining wall; ii) stability of a slope deposit; iii) failure mechanism of a shallow foundation. They will now be briefly described.

A. Lateral Soil Pressure on a Retaining Wall

The lateral pressure of the soil backfill on a retaining wall has two limit values. A minimum value is reached when the wall is allowed to move sufficiently away from the retained soil – this corresponds to the so called active limit state. Conversely, when the wall is forced to move a sufficient distance into the soil backfill a maximum value is attained, in the passive limit state.

These limit conditions have been recreated in the setup of Fig. 8, where the "soil" is materialized with wooden sticks of circular cross section.

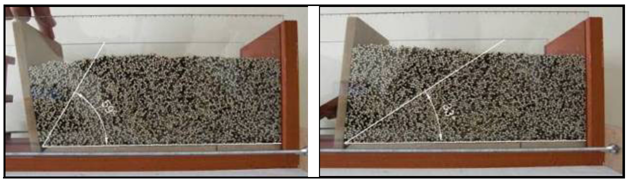

Figure 8. Active (left) and passive limit states

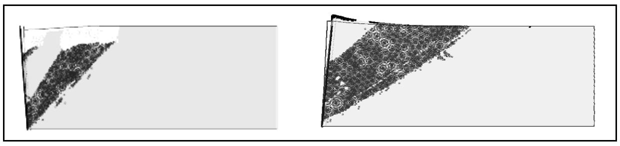

Figure 9. Active (left) and passive limit states obtained by numerical modelling

The geometry of the active and passive soil wedges agree well with the predictions of the Rankine theory and are reproduced with reasonable accuracy by a finite element numerical model, especially for the passive case, as shown in Fig. 9.

B. Stability of a Slope Deposit

The stability of slope deposits is frequently precarious. Such deposits exhibit slow, intermittent movement. As additional material slides down from the top of the hill and increases the weight of the active block, the whole mass moves slightly downhill until part of the weight of that block is transferred to the passive block. This type of instability is often triggered by heavy rainfall.

In the setup of Fig. 10 the deposits are simulated by a series of small wooden blocks lying on two wooden plates arranged with decreasing steepness. Once one additional piece is added at the top of the set a sliding movement occurs until a new equilibrium configuration is found.

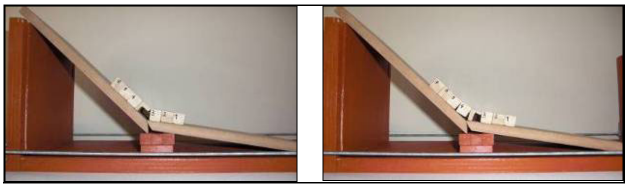

Figure 10. Initial state (left) and new equilibrium configuration after instabilization

C. Failure Mechanism of a Shallow Foundation

When the vertical load applied to a shallow foundation is increased until the bearing capacity of the soil is exhausted, the corresponding failure mechanism has the aspect illustrated in Fig. 11. The triangular zone I is punched down by the footing, while zone II is forced to move laterally and pushes zone III upwards.

In the setup of Fig. 12 wooden sticks of circular cross section were used once more to simulate the soil. The white line highlights the shape of the sliding surface of the failure mechanism.

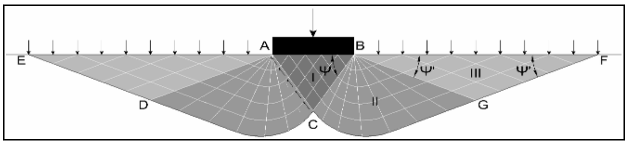

Figure 11. Failure mechanism of a shallow foundation

Figure 12. Failure mechanism of a small scale shallow foundation

V. FINAL REMARKS

The development of the tools described in this paper has involved multidisciplinary teams of teachers and students from the Departments of Civil, Mechanical and Informatics Engineering of FEUP.

The structural test frame was commissioned by the Civil Engineering Department and designed and built by Mechanical Engineering colleagues.

The SoftBeam virtual tool combined a structural analysis code prepared at Civil Engineering with a computer graphics module developed by Informatics students.

The seepage tank and the soil mechanics tools were developed within the framework of Master theses in Civil Engineering. Experimental equipment of this kind is commercially available and their main features have been thoroughly investigated as a preliminary step in the design process. The option for building instead of buying has been extremely rewarding, not only in terms of cost but especially in view of the multiple engineering skills that have been required and the creativity that has been stimulated in all those involved.

The development of the seepage tank and the soil mechanics tools have been a very comprehensive instance of project based learning performed by individual students which required initiative, engineering judgment, creative thinking, manual skills, persistence and determination.

The experimental results provided by the didactic setups have been systematically compared with those obtained by numerical modelling or the analytical solutions when available. This complementary approach has been found to be very fruitful. In the author opinion numerical modelling and computer simulation are undoubtedly very important but their combination with experimental work is the key to a richer and more balanced teaching/learning experience.

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