Linking Experiments with the Real World

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Abstract—**An interactive web application has been developed to provide a learning tool for soil mechanics students. Using digital video, html and javascript the interactive video provides some facts and figures about dams in general and embankment dams in particular, using a small scale experimental model and finite element numerical simulations to provide insight on groundwater flow phenomena in this type of works. The web application is able to supply further references through social networks in order to stimulate interest and promote deeper learning of embankment dam engineering and related phenomena.**

Index Terms—**engineering education; interactive video; groundwater flow; teaching tools.**

I. INTRODUCTION

Visualization is a fundamental component of the learning process, particularly in the engineering area. Visual aids play a major role in the understanding of physical phenomena and are instrumental in helping to link the perceived reality to the underlying theoretical models and their governing differential equations. Structural engineers have used photoelastic models to visualize the stress distribution in structural components many years before the emergence of finite element based numerical models [1]. Dams are important civil engineering structures whose world record height exceeds 300 meters [2].The vast majority of the world dams are embankment dams, massive water barriers made of natural geological materials excavated or quarried in the vicinity. Groundwater flow through their body and foundation must be carefully taken into account in the geotechnical design process. Small scale models are useful tools to understand groundwater flow phenomena and the visual cues they offer are powerful aids not only for the geotechnical designers but mostly in the teaching/learning process in Soil Mechanics courses, contributing in an effective manner to alleviate the difficulties often felt by students in this topic. The use of interactive video in this particular context provides additional flexibility and enhances the impact of the visual experience by merging in a single tool a vast amount of information of diverse and complementary nature, combining real world data with numerical simulations and experiments.

II. TYPES OF DAMS

Dams may be divided into two groups, according to their construction material: concrete dams and embankment dams. The former have three main types: gravity, buttress and arch (Fig. 1).

Gravity dams depend on their weight to resist the pressure of impounded water. Buttress dams are strengthened on their downstream face by a series of vertical elements called buttresses. Arch dams are curved in plan with a convex upstream face, which transfers the water pressure to the abutments by arch action. They are usually built in narrow rock canyons. Embankment dams are built with either earth fill or combined earth and rock fill. Around 75% of the world large dams are of this type [2] and will be further addressed in Section IV.

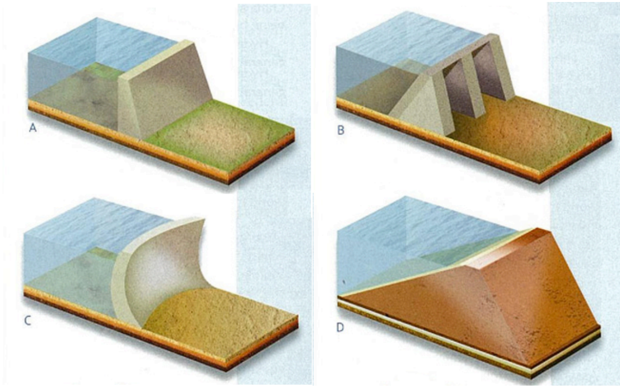

Figure 1. A – Gravity dam; B – Buttress dam; C – Arch dam; D – Embankment dam (adapted from [3]).

III. FACTS AND FIGURES ABOUT DAMS

Ancient dams were built for water supply and irrigation and to prevent flooding. Jawa Dam, the earliest record of dam construction in antiquity, whose remains date back to 3000 BC, was integrated in an elaborate water supply system for the town of Jawa in Jordan. There are also references to a 15-metre high masonry dam built around 2900 BC at Kosheish, in Egypt, to supply water to Memphis. Perhaps the oldest record of dam failure by overtopping is that of Sadd-el-Kafara dam, washed away by a flood of the Nile around 2700 BC [4].

The 7 metre high Quatinah Dam, a masonry dam in the Orontes River in Syria, is the oldest dam still in operation, having been built around 1300 BC for irrigation.

The ten oldest dams still in use are listed in Table I [5]. Most of them have been refurbished, upgraded, improved or reconstructed.

In what concerns reservoir storage capacity the world record of 148 km^3 belongs to the Akosombo Dam, a 134 metre high rockfill dam in the Volta River in Ghana. The world's ten largest dam reservoirs are listed in Table II.

The world highest dam is Rogun Dam in Tajikistan, with 335 metres. Table III presents a list of the world's ten tallest dams [2].

TABLE I.
TEN OLDEST DAMS IN OPERATION

Rank	Name (Country)	Date
1	Quatinah (Syria)	1319-1304 BC
2	Proserpina (Spain)	1st-2nd century AD
3	Cornalvo (Spain)	1st-2nd century AD
4	Kaerumataike (Japan)	162 AD
5	Kallanai (India)	2nd century AD
6	Sayamaike (Japan)	7th century AD
7	Manoike (Japan)	701-704 AD
8	Sadd-e Kobar (Iran)	10th century AD
9	Tonnur Kere (India)	12th century AD
10	Almansa (Spain)	1384

TABLE II.
TEN LARGEST DAM RESERVOIRS

Rank	Name (Country)	Height (m)	Capacity (km^3)
1	Akosombo (Ghana)	114	148
2	Guri (Venezuela)	162	138
3	W.A.C. Bennett (Canada)	183	74
4	Ataturk (Turkey)	169	48
5	Three Gorges (China)	181	39.3
6	Hoover (USA)	221.4	35.2
7	Garrison (USA)	64	29.3
8	Itaipu (Brazil / Paraguay)	196	29
9	Oahe (USA)	75	28.5
10	Fort Peck (USA)	76	22.7

Source – Wikipedia

TABLE III.
TEN HIGHEST DAMS

Rank	Name (Country)	Height (m)	Type
1	Rogun (Tajikistan)	335	Rock fill
2	Bakhtiyari (Iran)	315	Arch
3	Jinping (China)	305	Arch
4	Nurek (Tajikistan)	300	Earth
5	Xiaowan (China)	292	Arch
6	Grande Dixence (Switzerland)	285	Gravity
7	Xiluodu (China)	278	Arch
8	Inguri (Georgia)	272	Arch
9	Chicoasén (Mexico)	262	Earth
10	Vajont (Italy)	262	Arch

IV. EMBANKMENT DAMS

Embankment dam is the generic designation given to water retaining structures constructed with earth fill and/or rockfill materials, whose main purpose comprises electricity production, irrigation, water supply and flood protection [6]. These are complex civil engineering structures whose stability must be guaranteed with an ample safety factor for a variety of scenarios: the construction phase, the filling of the reservoir, the normal exploration, reservoir rapid drawdown and earthquake action. Their design includes a number of ancillary structures, namely

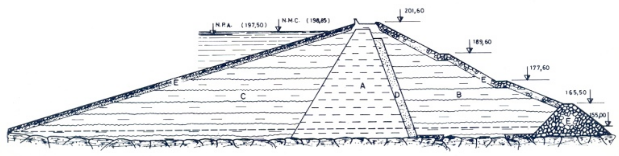

Figure 2. Embankment dam cross section (A – clay core; B;C – downstream and upstream shoulders; D – chimney filter; E – rockfill).

overflow spillways whose function is to prevent overtopping due to flooding that would lead to eventual failure.

Seepage or groundwater flow, the movement of water through the body of the dam, its abutments and the foundation soil, must be carefully controlled. One frequent approach is the inclusion of an impervious clay core in a central position of the dam body, surrounded by the upstream and downstream shoulders constructed with granular soil appropriately selected, whose external faces are protected by rock material from erosion due to floating debris and rainfall (Fig. 2) [7]. Seepage through the foundation may be controlled by the construction of an impervious curtain across the valley and reaching down to the bedrock or, at least, sufficiently deep beneath the body of the dam.

The transition zones between the clay core and the upstream and, particularly, the downstream shoulders must be carefully designed with the inclusion of filters, i.e., adequately graded granular material whose function is to retain finer particles eroded from the clay core, controlling in this way an internal erosion process that might otherwise go on undetected and eventually lead to disastrous consequences [8].

V. SMALL SCALE MODELS

A market search for laboratory equipment for small scale seepage studies revealed that prices were beyond our budget, which led to the design and development in house of an alternative solution at a much lower cost but with all the main features of those commercially available.

The main component is an acrylic tank with internal dimensions 2000mm long by 585mm high and 200mm front to back, with 12mm wall thickness. The closed hydraulic circuit is driven by a submersible electric pump (Fig. 3) [9]. The system has been conceived in order to perform several experiments that elucidate the qualitative and quantitative features of the physics of flow through porous media, enabling the verification of Darcy's law, the construction of flow nets and the visualization of flow lines associated to seepage phenomena in embankment dams, under sheet pile walls or into cofferdams.

Several small scale models of embankment dams have been studied with various seepage control devices such as a toe drain, a drainage blanket, a clay core and a chimney drain (Fig. 4) [10]. These devices are usually combined together in the design of real embankment dams. By considering them separately in different models the nature of their individual contribution and degree of effectiveness for seepage control can be fully appreciated.

Finite element modeling of the small scale dams has been performed with excellent agreement between experimental and numerical results, namely in what concerns the trajectory of flow lines obtained by the injection of colour fluid in the laboratory model (Fig. 5) [11].

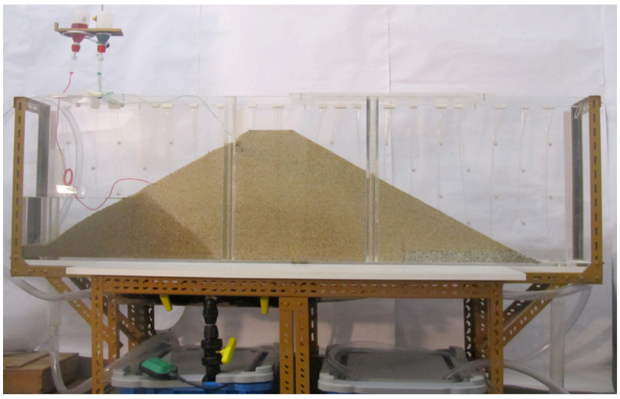

Figure 3. Frontal view of the didactic equipment for seepage studies.

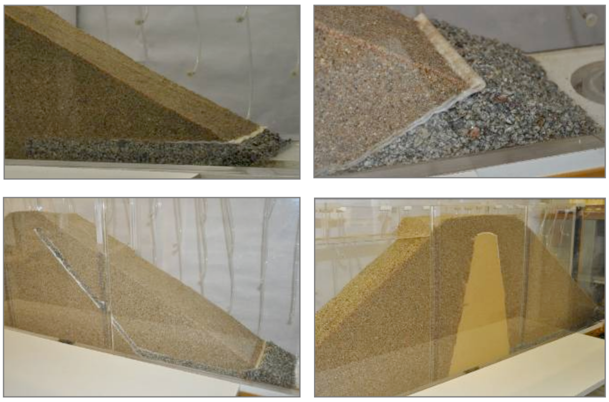

Figure 4. Drainage blanket, toe drain, clay core and chimney drain (clockwise from top left).

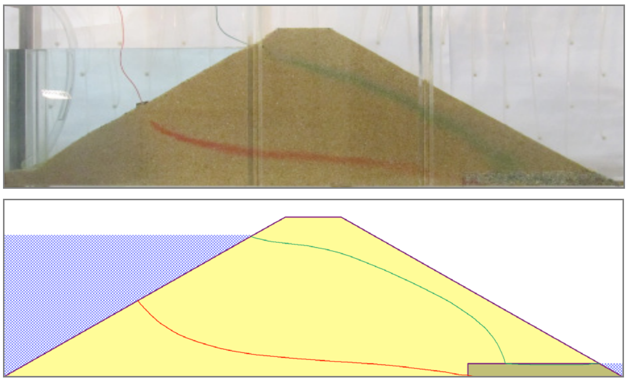

Figure 5. Experimental and numerical results for flow line configuration in small scale dam with toe drain.

VI. INTERACTIVE VIDEO

Films have been since their invention a notable mass media technology with a remarkable ability to entertain and inform people within a wide cognitive level range. Yet effective communication requires adequate identification of the target audience. Plans are the film basic units. In order to convey every detail to the audience scenes should be split into plans [12]. To create scenes it is important to create a story that tells the audience something they care about. In an educational context this factor upholds the user motivation [13]. Nevertheless it is also important to guarantee the information accessibility and adequate context guaranteeing that user inputs and social context analysis is taken into account, especially during the story construction, in order to provide an adequate pedagogical experience and adequate user interaction metaphors. It is also important to clearly communicate the learning objectives when using an internet application with learning purposes [14]. This leads to a major concern, namely how to develop a consistent story through the learning experience in order to integrate educational characteristics that prevent loss of interest [13].

The first interactive film ever made is Kinoautomat by Radúz Činčera where the audience chooses the scenes to be played after a moderator presents the two possible alternatives. This film was created for Expo'67 in Montreal, Canada [15]. Nowadays, with the new HTML 5 standards [16] it is now possible to access video as a web object allowing it to be part of a connected web that creates links to new sources of information and provides new methods of interaction with that information [17]. There are several frameworks that allow web development connecting video with other elements such as social networks, cueing actions on the webpage through the video's timeline or referring to additional references [18]. Popcorn.js is one emergent technology, developed by Mozilla, which turns media into fully interactive JavaScript objects, so that media objects can both trigger and listen to events. It enables developers to cue events along a media timeline [19], making the visualization of media fragment annotations much easier, combined with plug-ins in order to interact with common services and APIs [18]. It is well documented with many examples from simple subtitling to integrating contents with social networks, Google services or Wikipedia, to include custom javascript code. Media playback is accessible via popcorn.play(), popcorn.pause(), and popcorn.currentTime (seconds), which allows to jump to any point on the timeline. Popcorn.js also provides popcorn.cue() whereby it is possible to launch custom actions on the interactive video [19]. Popcorn is the most mature development framework on interactive web video available from a list of frameworks [18].

As the whole pedagogical experience is programmed on a webpage it is possible to record the user inputs during video playback (play, pause, rewind, skip) or an interactive video (repeated actions) evaluating them in order to perceive the user main difficulties or which contents are considered most important or difficult to understand [20]. This can be an important asset on the development of pedagogical tools on the web leaving the traditional example tracing model found on most tutorial videos and moving towards a model-tracing tutor where the system is able to interpret students' behavior and adapt the learning experience based on their cognitive level [21]. Online experiments and tutorials share the advantage of being available from any remote location, but they are interpreted by each user based on his pace of perception and cognitive knowledge [22]. To fully guarantee the users' adequate perception it is important to perform an extensive planning of the contents development phase [22] whereby all the variables related to social values and user perception can be evaluated and conceived. Visual information does not stand by itself. Its interpretation is based on the users' cognitive knowledge which is founded on their lifetime experience and social context [23].

Before developing an interactive learning solution it is important to identify the target audience, i.e. for which students it will be developed, in which context it will be used and when it will be used on their learning stages. These variables determine the user's experience and influence the pedagogical success.

VII. INTERACTIVE VIDEO LEARNING TOOL

The interactive video experiment is integrated in experiment@portugal [24], a web page that disseminates the national potential in online experimentation provided by higher education institutions in Portugal [25] and available on the platform pt.lab2go (http://pt.lab2go.net/lab2go/) [26]. This project aims to develop adequate strategies concerning hardware, software, sound and image technologies, web seminar facilities, booking tools, support platform and web server management for remote applications in learning and training contexts.

The interactive video is used to provide detailed information to students about a remote sensitive experiment (available on request) concerning seepage phenomena in embankment dams (Fig. 6).

The interactive video learning tool has been developed using popcorn.js technology and its video production has involved filming from a frontal perspective a small scale model of an earth dam with a drainage blanket during the reservoir filling operation and, subsequently, during the gradual development of two flow lines visualized by injection of color fluid. In this way it is possible to witness groundwater flow as it progresses, which offers a live perception of the physical phenomenon that is expected to provide a positive contribution from a cognitive point of view. It is worth mentioning that groundwater flow is a topic in which students typically experience some difficulties in grasping the fundamental concepts. Therefore this video constitutes a badly needed complementary learning tool which shall improve user understanding and play an important pedagogical role. This effect can be further expanded by the inclusion of additional hypermedia elements made possible by the flexible nature of interactive video technology.

Using javascript coding combined with popcorn features custom actions can be launched through the video timeline. It is possible to ask the user to identify elements of the embankment dam morphology or pose questions of soil mechanics in order to recognize if he understands the contents he is being exposed to. This can be a good benchmarking test, allowing the tutor to assess his students' knowledge and thereby adapt the learning experience to its audience.

One feature envisaged for this experience is to take advantage of 3rd party service integration on popcorn.js and complement the information about how embankment dams are designed and built, their internal mechanics, their function and origin, with data about their location and an aerial view. The database of the Portuguese National Commission of Large Dams is used to put students in close contact with their national dam context. This is a huge database containing technical information, construction plans and photographs. One additional feature under consideration is to determine the user's current location and show him, through Google maps integration, which dams are nearest.

Integration with YouTube service has also been explored and allows demonstrating how massive can be a dam disaster and how large its implications in geographical terms. Accidents by internal erosion like those of Baldwin Hills Dam [27] and Teton Dam [28] or by overtopping in laboratory simulation [29] are good examples to illustrate the forces involved on dams and how dangerous they can be to modern society if dams are not correctly designed, built and maintained.

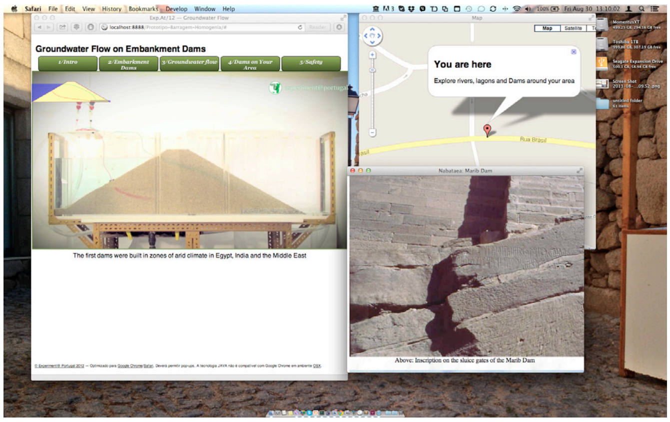

Figure 6. Screen shot of the interactive video on groundwater flow in embankment dams.

VIII. FINAL COMMENTS

Several small scale models of embankment dams with alternative configurations of the seepage control devices (as illustrated in Fig. 4) will be the next steps and augmented reality will also be applied as an additional educational tool in order to make the system more flexible to the users while exposing students to new facilities based on emerging technologies.

In fact, this system will have a complete set of new tools - it is accessible by internet for scheduled demos, it will offer an interactive video documenting all the aspects already mentioned and it will provide the opportunity to enjoy an augmented reality application, in order to increase student immersion in the system but also avoiding all the preparation time and manpower required for altering the small scale setup for a new embankment dam configuration.

The interactive video, with both Portuguese and English versions, is available on the internet and student feedback will be collected and analysed during the academic year 2013-2014.

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