Design of seepage flow virtual laboratory tests in the discipline of Soil mechanics. An alternative proposal with multiple teaching advantages

[1]Iván Alhama Manteca and [2]Pablo Ortiz García

[1]Civil Engineering Department, EICM
Campus Alfonso XIII 30203 (UPCT)

Subject:

Innovation experiences based on the use of TIC
New scenarios of teaching and learning

Abstract

The characteristics of the laboratory or field tests, to be developed by the students, in disciplines of technical carriers such as Mines and Civil Engineering are qualitatively and quantitatively different that those related to basic disciplines such as Physics, Chemistry or Graphical Representation. However, these are quite fundamental for a complete formation of the students in order to complement their theoretical teaching; the practical e experience acquired by the engineer in laboratory and field is quite essential for their professional future. The drawing up virtual laboratory tests, always as alternative to real tests, when they are correctly carried out with well-established aims, can suppose an interesting solution since they offer a large number of advantages. In this work the experience of making up a didactical unity of a virtual laboratory test, on the issue of flow networks in the discipline of Geothenics, bring together the subjects that the students must know about the matter. To this end a suitable code is developed that goes further the flow network construction. The virtual test also contains complementary and optional exercises, with auto-evaluative character, that students must fit in their own computer for the compliance of all the subjects.

Keywords: Virtual teaching, Laboratory tests, Software development, Autoevaluative practical tests

Resumen

Las prácticas de laboratorio en asignaturas propias de disciplinas de especialidad en carreras de ingeniería tienen ciertas características que las diferencian cualitativa y cuantitativamente de otras pertenecientes a asignaturas comunes como la Física, la Química o la Expresión Gráfica. Sin embargo, una formación profesional correcta requiere obviamente la asistencia a laboratorios reales e incluso al campo para completar la formación teórica que se imparte en clases de teoría y problemas. La elaboración de prácticas, siempre alternativas, de carácter virtual, cuando se programan con objetivos bien definidos, puede representar una solución interesante que tiene múltiples ventajas. En este trabajo se presenta una experiencia consistente en la elaboración de una unidad didáctica de prácticas de laboratorio

virtual en la temática de redes de flujo, dentro de la asignatura de Geotecnia de las carreras de Ingeniería de Caminos e Ingeniería de Minas, que aglutina los objetivos que el alumno debe conocer sobre la materia. Para ello se usa un código propio, desarrollado a este fin, que transciende de la propia elaboración de la red, auto-evaluativo y con propuestas complementarias y opcionales que el alumno debe completar como trabajo individual.

Palabras Claves: Enseñanza virtual, Prácticas de laboratorio, Desarrollo de Software, Pruebas prácticas de autoevaluación

The laboratory tests in engineering carriers

Most of specialized disciplines in engineering carriers require a certain number of laboratory essays or tests that allow the students to achieve a complete knowledge of the theoretical contains of such matter. Principles, laws, theorems and problems are planning to be explained in class and practical applications are carried out in laboratory or field. This occurs in many disciplines such as, for example, electrical technology, materials engineering, fluid dynamics, strength of materials, etc.

The complexity of laboratory essays in most of these fields involved the solution of some overcoming:

i) Relative small number of students in the essay,
ii) Special attention of qualify personal (currently more than one professor),
iii) Large duration of the essays,
iv) Laboratory specialized equipment,
v) A suitable and detailed programming of the test…

Due to this problematic, the main result is that the tests are very expensive, representing a large percentage of the final costing of the teaching. Also, as a consequence of the peculiarities of these tests, the equipment´s maintenance is continuous since its damage is frequent due to an inappropriate manipulation of inexpert and daring students; this enhance, even more, the cost of teaching. The reality fact derived of all these overcoming is that a good percentage of planning tests are, simply, not carried out and students finish their carrier without a suitable knowledge of these practical teaching.

For example, of the three more complex tests that are programming to be carried out in the geotechnical laboratory of the Highway and Mining School of the Technical University of Cartagena (permeability determination, shear stress machine and consolidation test), only some of them has been implemented along last years (the years that the highway or civil engineer carriers is being developing). In fact, consolidation test has been teaching for the first time the current course 2013-2014.

An added overcoming of this kind of tests is the large time required for its fulfillment. So, the consolidation requires of the order of a hundred of hours to be correctly and completely made. This, of course, prevents an appropriate scheduling of this laboratory work and, in general, of the practices of the complete course. To carry out this test, the approximately 50 students were organized in 10 groups of 5 students that go to the laboratory successively taking note of the required data related to time and displacement of the sample; information obtained by each group was transfer to other groups to realize the final calculus, determinations and graphics. In a first session of the test, an explanation of the test was given to all students.

It is also interesting to point out something more in relation with the teaching aims marked in each test. Generally, two objectives are proposed:

i) to familiarize the student with the management of the equipment, and
ii) to organize a protocol capable to instructing the student on the detailed performance and searching of results of a particular application.

However, if we want to find other results caused (for example) by the change of a given parameter, or of a certain boundary condition, as well as to put in practice other application of the same equipment, we are forced to start from the beginning with the new task, carrying out all the necessary real steps needed for the new experiment.

Virtual practices carrying out through codes, however, avoid to repeating nearly the complete test since it only requires to implementing the new data before running the program in suitable codes. Students are able to simulate different values of a given physical or geometrical parameter of the experiment, different types of boundary conditions (or values for one or more of the parameters that define them), and more and more. All of this carried out with relatively small computational times (something beyond imagination if they were carried out in laboratory).

The design of good virtual practices is not free of work on the part of the teacher and requires a number of skills and specific knowledge apart of having a deep understanding of the discipline. Particularly the knowledge of

i) all the relative to a programming language to design the model to be numerically solved or simulated,
ii) a code to program the communication interface to introduce data and ask for the output representation, and
iii) a code to manipulate and post-process the output data in order to be understood by simple inspection of graphics.

The virtual practice developed in this work is a good example about the possibilities of this tool in the teaching of engineering and technical disciplines. It refers to the so named flow networks (seepage flow) [1,2]; graphics schemes that allow the civil engineer to search the flow of groundwater under civil structures such as concrete dam or sheet piles. This may be considered as a standard test due, on the one hand, to the large number of parameters (physical and geometrical) that can to be change in the experiment and, on the other hand, to the different types of standard structures that can be studied and simulated.

The more important advantage is that the requirements demanded for the design of the model to be solved numerically is within student´s reach since it is based on the known electrical analogy [3], a discipline whose fundamentals are subject of study in the first course of the carrier. At this stage, the virtual test is in preliminary developing; two steps have been solved, the design of numerical models (using the network method [4]), their simulation in the free standard software Pspice [5] and the creation of the post-processing programming routines in Matlab [6] for showing graphically the output results. The communication interface needed to introduce the input data of the problem as well as the interface to ask for the kind of output representations is hold.

The virtual test of flow networks (seepage flow)

Mathematical and network model. Governing equation in plane scenarios of steady state groundwater flow under different types of structures such as concrete dams, Figure 1 (a), weirs founded and cofferdams, Figure 1 (b), on homogeneous, anisotropic and permeable soils, is that of Laplace´s.

$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} = 0$$

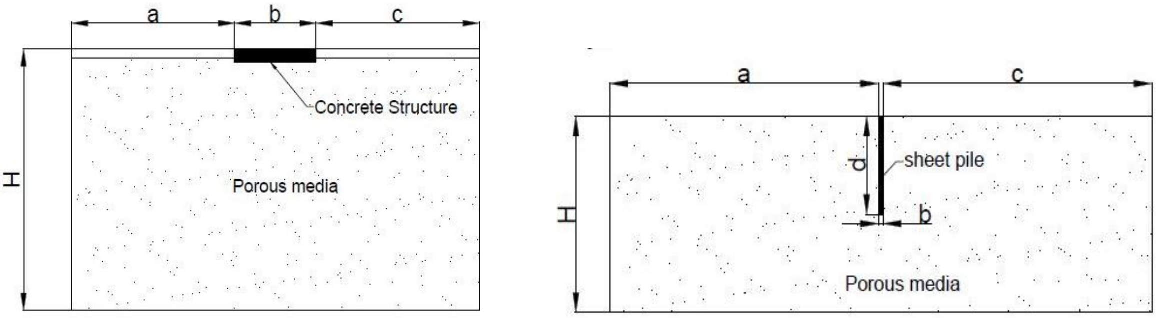

Figure 1 Scheme of the scenario.
Left(a): concrete dam. Right (b): sheet pile cut-off wall

Boundary conditions are the following: impermeable flow at bottom, right and left sides of the domain, and iso-piezometric representative constant values of total head at both sides of the top boundary in order to water be forced to flow from the upper left boundary to the upper right´s. In mathematical expressions, boundary conditions are given by:

i) y=H, $0 < x < l_o$ $\Rightarrow$ $h = h_a$
ii) y=H, $l_o+l_1<x<L$ $\Rightarrow$ $h = h_b$
iii) (1): y=H, $l_o < x < l_1$; (2): x=0, y; (3): x=L, y and
(4) y=0, x $\Rightarrow$ no flow

The larger the lengths at both sides of the structure (concrete or sheet pile), the more representative and real the model to be analyzed.

Laplace´s is a kind of equation familiar to the students that have passed the study of electrostatic fields within the discipline of Physics in the first course of Graduate [7]. Total head or piezometric level is assumed as dependent variable while space (2-D) and time are the independent variables. Water flows through the pores of the soil, thanks to the existing pressure gradient, reaching nearly instantaneously the steady state final pattern.

The network model of a elementary cell or volume element is a simplification of that developed by the research group 'simulation by networks' of the UPCT; a complete information related to the design of the whole model, including the boundary conditions, and to the programming routines for graphical representation can be found in [8]. A electrical scheme of the elementary cell is depicted in Figure 2. Since the model only contains resistors and batteries (the last to implement the constant piezometric level at the top boundary, few programming rules have to be used for the design. Once the file of the model is ready, it is run in the software of circuits simulation code Pspice and the output data graphically represented by routines of Matlab.

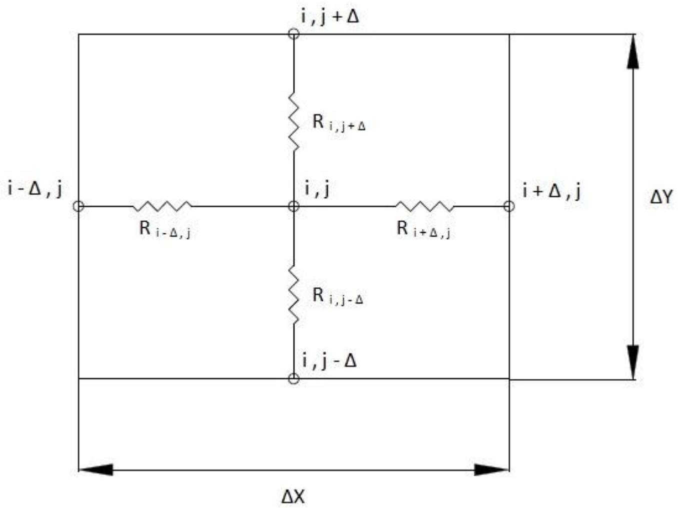

Figure 2 Network model of the elementary cell or volume element

Geothenic scenarios

Two typical scenarios are studied (Figure 1). The first for the study and solution of seepage flow along a concrete straight dam (left of the figure) and the second for the seepage flow along a sheet pile cut-off wall (right of the figure), both driven in homogeneous soil layer of infinite thickness to approximate the real structures. Even though the relatively small number of physical and geometrical parameters (or physical characteristics) that influence the steady state patterns of flow lines and iso-piezometric lines, they are enough as to be considered a relevant material for a laboratory virtual test. The list of these parameters is shown in Table 1.

Physical parameters	k_x: horizontal permeability
	k_y : vertical permeability
Geometrical parameters	a, length of the domain at the left of the dam (or sheet pile)
	b, thickness of the dam (or sheet pile)
	c, length of the domain at the left of the dam (or sheet pile)
	d, buried length of the sheet pile
	H, depth of the domain

Table 1 Physical and geometrical parameter to be controlled

The main unknown of interest is the total seepage flow that drives the underground porous media from the high piezometric location (top-left boundary) to the less one (top-right boundary), a variable that can be read from the steady patterns. Among the main qualitative aspects that can be studied changing one or more of the parameters are:

i) The length of the domain that approximate the model to the real x-infinite scenario,
ii) The influence of the dam thickness on the total seepage flow driven,
iii) The effect of the isotropic permeability values on the total flow driven,
iv) The effect of the ratio k_x/k_y
v) The depth of the buried sheet pile and its influence on the total flow,
vi) The proportionality between piezometric level difference and total seepage flow,
vii) The effect of the depth of the scenario on the total seepage flow

Heterogeneous domain (or domain formed by horizontal or vertical layers of different permeability) can be easily implemented by assuming suitable values of the resistors of the network model in each layer; this aspect has not been driven in this work although the provided routines provide such possibility.

The sub-soil domain has been separated in three (six) regions for the concrete dam structure (for the sheet pile´s) for a clear vision of the different boundary conditions existing. These regions and their reticulations (mesh) are shown in Figure 3 for the sheet pile case.

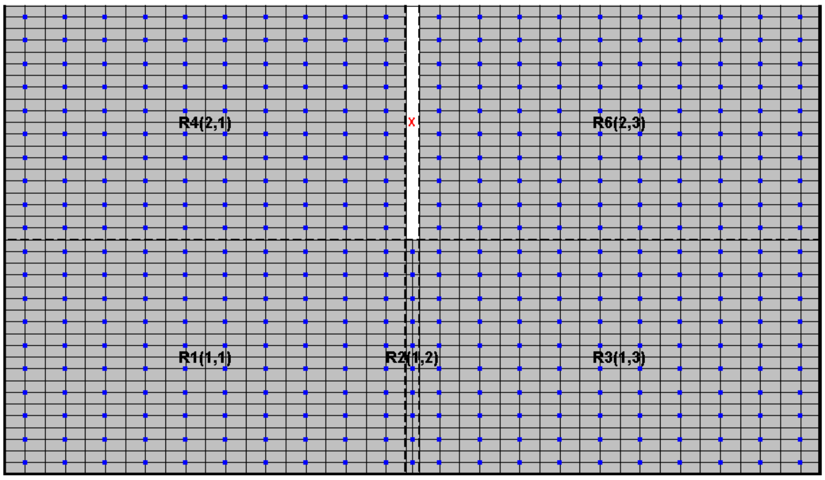

Figure 3 Regions of the domain for the sheet pile structure

Simulations

As representative results of the virtual laboratory test, some simulations have been carried out. For all them output data from Pspice were transported to Matlab for a suitable representation in the form of standard patterns. As regards the concrete dam three scenarios of the same geometry have been simulated changing the value of the hydraulic permeability; for two of then anisotropic values were assumed. Table 2 shows the set of values of the parameters.

Cases	k_x (m/s)	k_y (m/s)	a (m)	b (m)	c (m)	H (m)
I II III	0.01 0.01 0.01	0.01 0.02 0.005	30	6	30	20

Table 2 Scenarios of the seepage under concrete dam

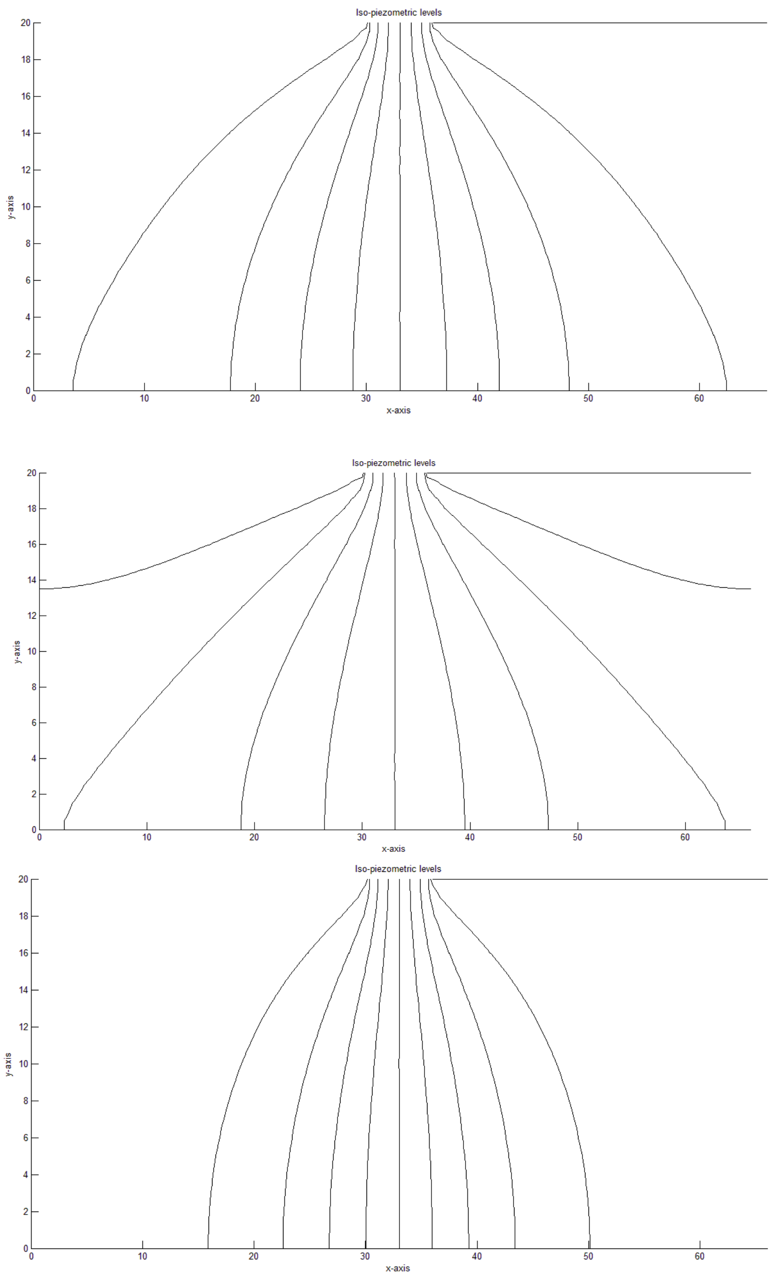

Figure 4 Patterns of iso-piezometric levels of cases I (a), II (b) and III (c)

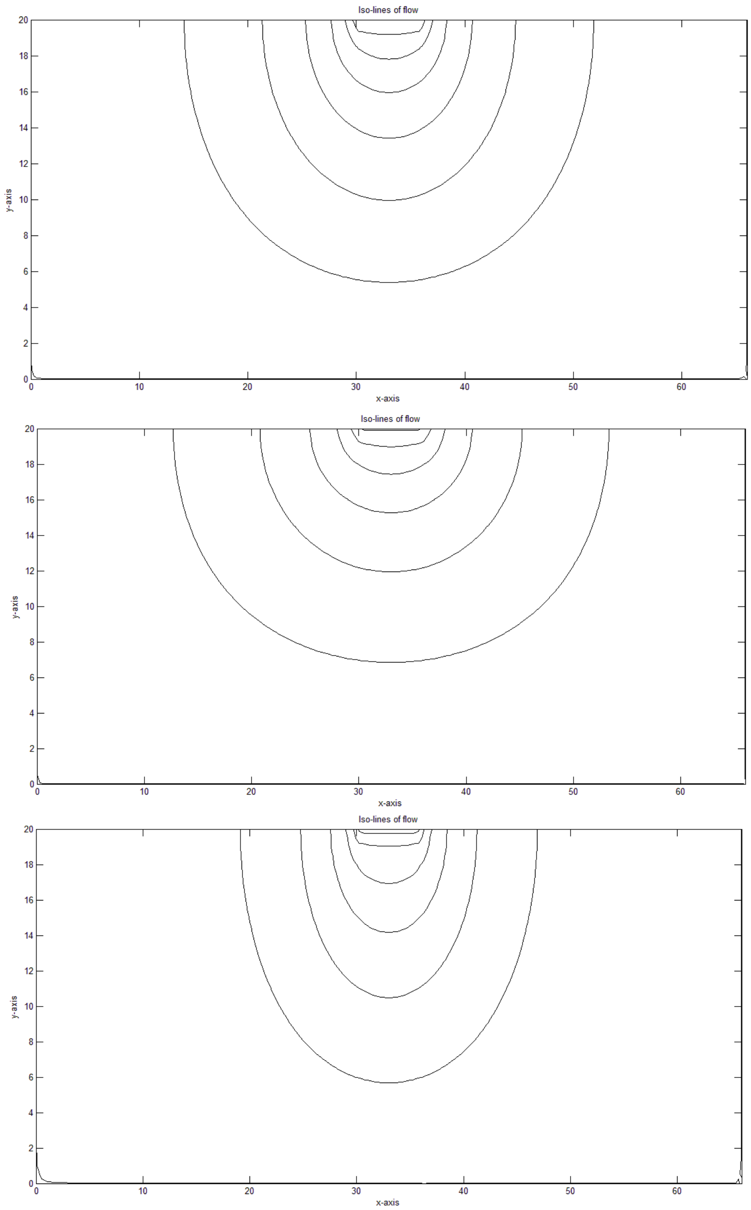

Figure 5 Patterns of iso-lines of flow. Cases I (a), II (b) and III (c)

Figures 4a, 4b and 4c show the iso-piezometrric lines for the cases I, II and III of the table, respectively. The ratios a/b and c/b are large enough as to considered that the influence of underground soil further than the domain is negligible. The effect of anisotropy is clearly appreciable in the patterns; the comparison of cases II ($k_x > k_y$) and III ($k_x > k_y$) allows the student with qualitative information as to infer the influence of the anisotropy effect, a work that the student must justify.

The flow iso-lines patterns for these three cases are shown in Figures 5a, 5b and 5c. From the complete results, after representing the patterns of each case in a same graphic, a calculation of the total seepage flow can be derives.

For the sheet pile structure, Figures 6a, 6b and 6c show the iso-piezometric lines of the cases IV, V and VI of Table 3, respectively.

Cases	k_x (m/s)	k_y (m/s)	a (m)	b (m)	c (m)	d (m)	H (m)
IV	0.01	0.01					
V	0.01	0.02	30	0.1	30	10	20
VI	0.01	0.005					

Table 3 Scenarios of the seepage under sheet pile cut-off wall

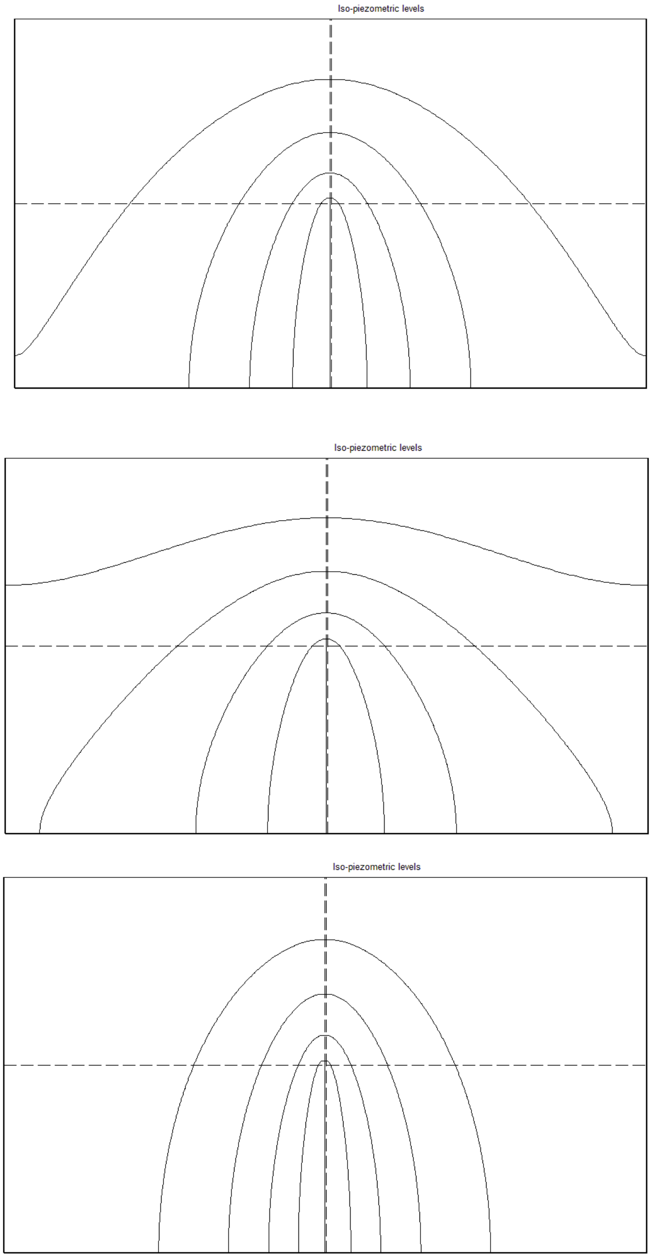

Figure 6 Patterns of iso-piezometric levels of cases IV (a), V (b) and VI (c)

Again, the effect of the anisotropy in permeability parameter is also appreciated.

Summary

The possibility of virtual laboratory test in the field of civil engineering has been exploited by proposing a case belonging to the discipline of geothecnic, the design of flow networks (seepage groundwater flow under civil constructions). In contrast with experimental or real tests, different cases related to different values of some of the parameters that influence the solution can be simulated with small computational times. This allows to carry out the experience in suitable times as well as to recognize a variety of different aspects of the test that would not be studied by a real experiment. The design of the model and programming routines required for the implementation of the experience is within the scope of knowledge of a student that has pass the Physics and Mathematical disciplines of first courses of Graduate technical carriers.

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