Virtual Laboratory Work in the Course of Hydromechanics «The Study of Filtration in Sandy Soil at Darcy Device»

PRINCIPLES OF INTERACTION WITH THE VIRTUAL MODEL OF THE LABORATORY EQUIPMENT

The simulation model of the laboratory equipment is an interactive geometric structure placed in a virtual three-dimensional space. Observation of objects is carried out using a virtual camera. In the basic (free) mode, the camera can rotate around the focus point (figure 1). The focus point of the camera can move in the vertical frontal plane. In addition, the camera can distance itself relative to the focus point for an arbitrary distance bounded by the dimensions of the work space of 3D scene.

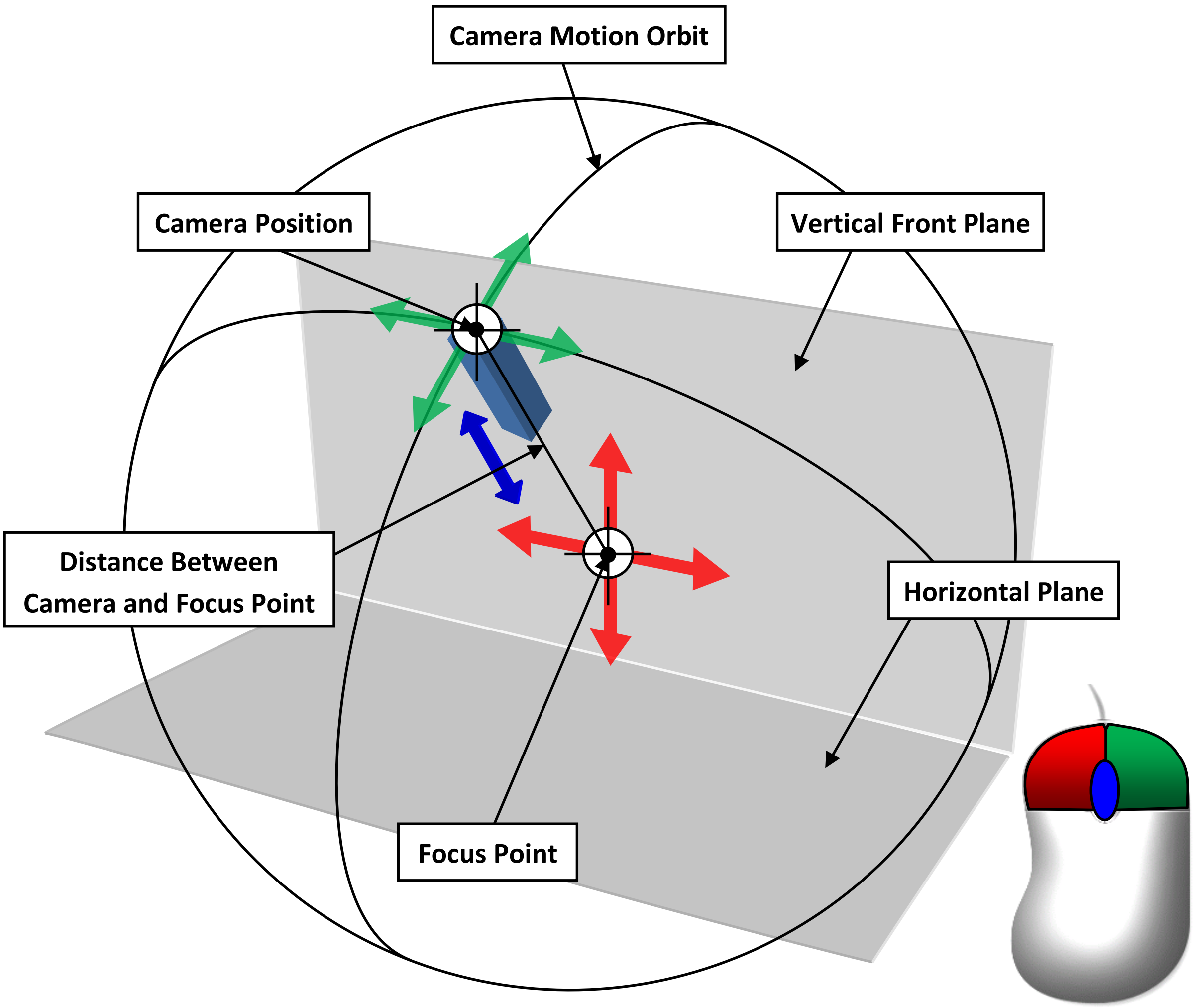

Figure 1 – Principle of the Camera Control in Free Mode

Basic manipulations with the camera in a free mode are carried out using a computer mouse. Herewith pressing and holding the left mouse button with the accompanying movement of the mouse moves the focus point of the camera in the frontal plane of work space. Clicking and holding the right mouse button while moving the mouse causes the camera to rotate relative to the focus point. The angles of rotation (azimuth and elevation) of the camera are limited by the dimensions of the 3D work space. The distance between camera and focus point is changing by rotating the mouse scroll wheel in the forward and reverse directions.

Note: in some virtlabs, the focus point may move in a horizontal plane!

In addition to the free mode, the camera can switch to individual elements of the laboratory equipment. Switching the camera to the individual object is performed by hovering the mouse over the object with a subsequent single click of the left mouse button. In this case, the camera can take a static position or be able to move in a vertical plane by hovering the mouse pointer to the edges of the screen or using the keyboard arrow keys. The clicking on an arbitrary area of the screen is return of the camera to basic mode.

The interaction with the control elements of the simulational laboratory equipment is carried out by hovering the mouse over the object and then pressing (or a single click) the left (or right) mouse button. Specific of the control for different elements may vary. For example, continuously regulating elements (flow control valves, etc.) require holding the left or right mouse button to change their state. Elements of discrete action (gates or latches) require a single click of the left mouse button.

At the moment of hovering the mouse pointer over the object, manipulations with the camera are temporarily unavailable. Similarly, when manipulating the camera, it is not possible to perform actions on the controls elements of the lab equipment.

VIRTUAL MODEL OF THE LABORATORY EQUIPMENT

A simulation model of a laboratory equipment (Figure 2) includes a pressure tank (1) from which water enters a vertical column (2) with a square cross-section with internal dimensions of 10×10 cm, filled with five layers of sandy soil of various grain sizes. The thickness of each layer of homogeneous soil is 10 cm. At the boundaries of the layers there are fittings to which glass piezometers (3) are connected through rubber hoses for measuring heads. The water supply to the column is controlled by a valve (4). To maintain a constant water level above the soil surface in the column (in order to ensure the steady movement of the filtration flow) there is an overflow pipe. The change in the experiments of the head gradient J (and, consequently, the filtration flow Q) is achieved by changing the height of the drain device (5) connected by a corrugated rubber hose to the bottom of the column. Measurement of the filtration flow rate of water Q is carried out by a measuring vessel (6) with a scale (in cm^3) printed on the wall and a shut-off valve (7) in the lower part. The time t of filling filtered water with the desired volume W is measured by a stopwatch. Water temperature τ, °C, measured by a thermometer.

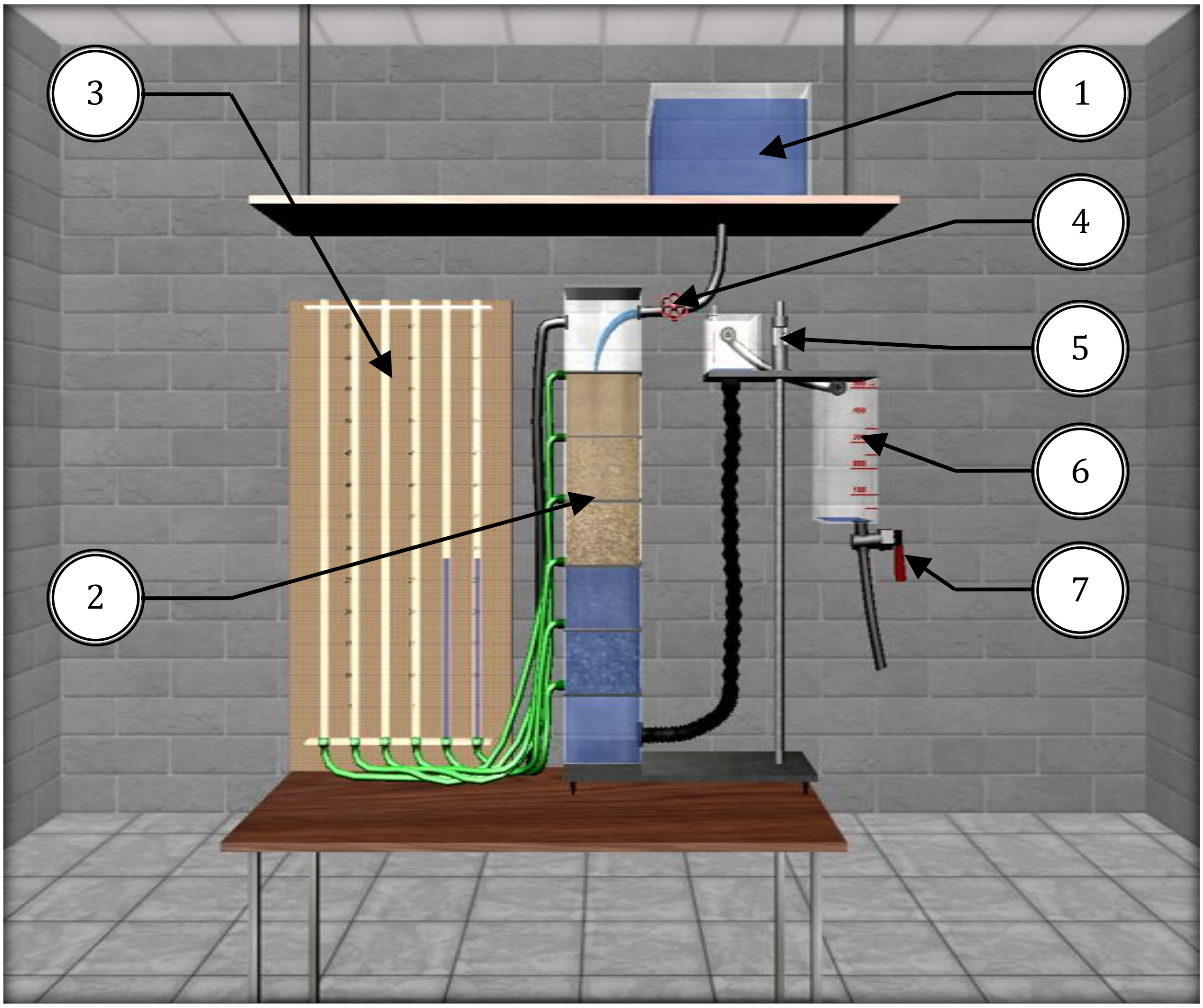

Figure 2 – Image of a Simulation Laboratory Equipment for Experimental Study of Filtration in Sandy Soil at Darcy Device

PHYSICAL PROCESS DESCRIPTION

Filtration is understood as the movement of water in the pores of water-saturated soil. Knowledge of the filtration laws is necessary in the design, construction and operation of industrial, residential and public buildings, hydraulic structures included in environmental management systems and environmental engineering.

In particular, knowledge of the laws of filtration is necessary to determine the flow of groundwater to the pits of buildings under construction, drainage and water intake devices, to calculate the settlement of foundations and calculate water losses through earth dams and dams.

The movement of groundwater, as well as flows in pressure pipelines and open channels, can be steady and unsteady, uniform and uneven, pressure and non-pressure.

The ground water movement mode can be laminar or turbulent.

In this lab work, the steady-state pressure filtration under the laminar mode, described by Darcy's law, is studied. The analytical expression of this law is usually written in two forms:

$$\upsilon = k \cdot J \tag{1}$$

and

$$Q = S \cdot k \cdot J \ , \tag{2}$$

where υ – filtration velocity, i.e. adaptive velocity

$$\upsilon = \frac{Q}{S} \ , \tag{3}$$

Q – actual (fact) filtration rate; S – the surface area of the filtration stream, consisting of the total cross-sectional area of the pores S_{pore} and particles of the skeleton of the soil S_{grain}, i.e.:

$$S = S_{\text{pore}} + S_{\text{grain}} \ , \tag{4}$$

k – the filtration coefficient – a scalar value, usually having a dimension of cm/s or m/day and characterizing the permeability of the soil; J – head gradient – the ratio of the difference between the total heads $H_1 – H_2 = h_{1-2}$ at two points of the soil flow lying on the same streamline to the distance between them l_{1-2}, measured along this line, i.e.:

$$J_{1-2} = \frac{H_1 - H_2}{l_{1-2}} = \frac{h_{1-2}}{l_{1-2}} \tag{5}$$

The value of k is determined for each type of soil empirically (at a constant temperature of the filter fluid). In the reference literature, soil filtration coefficient values are usually given at a temperature of τ=10 °C.

For the transition from the value of the coefficient k_τ, obtained at a temperature τ, other than 10 °C, to its value at 10 °C (k_{10}) the formula is used

$$k_{10} = \frac{k_\tau}{\Delta\tau} \ , \tag{6}$$

where $\Delta\tau$ – the temperature correction, °C, calculated by the empirical formula

$$\Delta\tau = 0.7 + 0.03\tau \ , \tag{7}$$

In the case of filtration, the velocity head is ignored, so the total head is considered equal to the hydrostatic, i.e.

$$H = z + \frac{p}{\rho g} \tag{8}$$

Darcy's law shows that the filtration rate is proportional to the head gradient, or, in other words, the head loss is linearly dependent on the filtration rate.

Note that the actual velocity of the fluid in the pores of the soil

$$\upsilon_d = \frac{Q}{S_{pore}} \tag{9}$$

The velocities υ_d and υ c are related by the relation

$$\upsilon_d = \frac{\upsilon}{n} \tag{10}$$

where n – soil porosity:

$$n = \frac{S_{pore}}{S} \tag{11}$$

Expression (10) is obtained as a result of a joint solution of dependencies (3) and (9).

Figure 3 shows the dependence of the filtration rate υ on the head gradient J, and figure 4 shows the head epure.

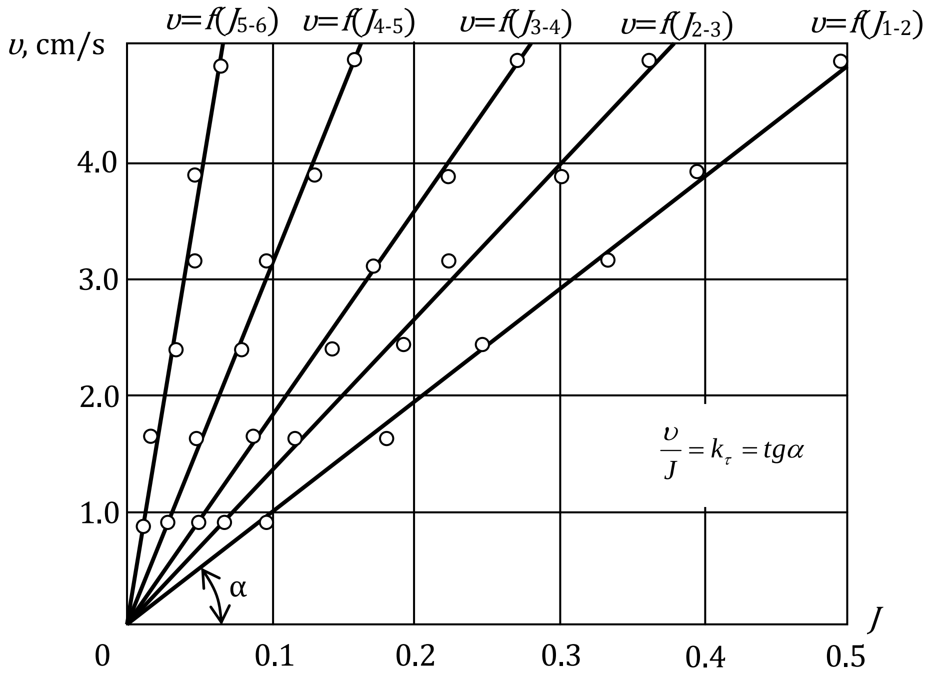

Figure 3 – Dependence of the Filtration Velocity υ on the Head Gradient J

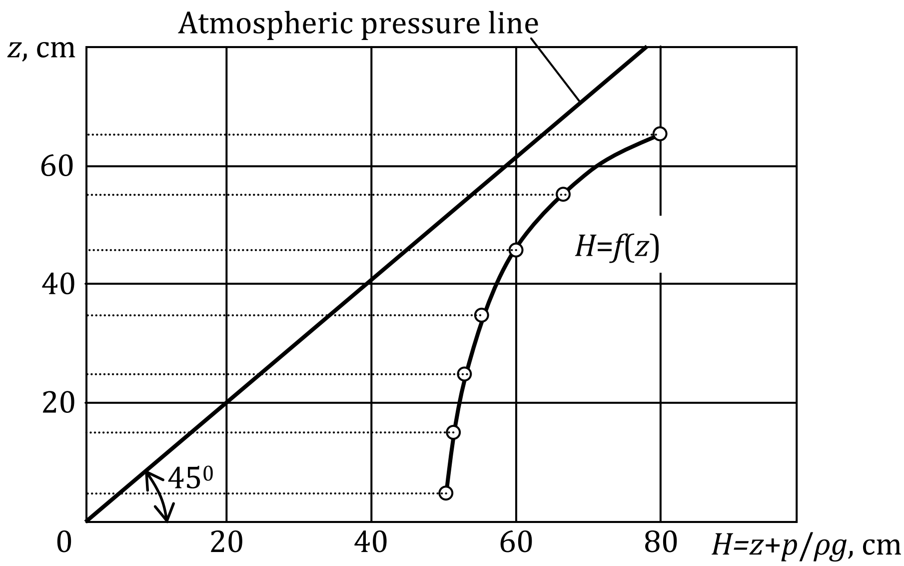

Figure 4 – Head Epure

LABORATORY WORK DESCRIPTION

Laboratory Work Objectives:

1. Verify the validity of Darcy's law by plotting on a scale (according to five experiments) graphs of the dependence of the filtration rate υ on the head gradient J for five types of sandy soil with different particle sizes (Figure 3).

2. Determine from the graph $\upsilon=f(J)$ for one type of sandy soil (indicated by the teacher) the average value of the filtration coefficient k_τ and indicate it on the graph (Figure 3).

3. To plot, on the basis of the data of one experiment indicated by the teacher, a head epure, i.e., a graph $H=f(z)$ of the head change H along the filtration path (Figure 4).

The Order of the Work and the Processing of Experimental Data:

1. At the highest position of the drainage device, conduct experiment №1: determine the water levels in the piezometers, that is, the heads H at points 1…6 of the filtration flow; measure the excess z of these points over the comparison plane; measure the volume W of water filtered through the soil in a measuring vessel, the duration of filling the volume and the temperature of the water τ °C. Record the obtained data in the table 1.

2. Lower the drain device by 5…10 cm and, after waiting a while, so that the filtration mode is established, perform experiment №2, measuring and recording in table. 1 are the same values as in experiment №1.

3. In total, it is necessary to do five experiments, lowering the drain device in each subsequent experiment by 5…10 cm.

4. To process the experimental data and the processing results are presented in table. 1 (items 6–12).

5. Build to scale according to the table. 1 graph $\upsilon=f(J)$ for all five types of the studied soil (Figure 3) and head epure $H=f(z)$ for one of the experiments indicated by the teacher (Figure 4).

6. Give a conclusion of the results of the work.

Table 1 – Results of Measurements and Calculations

№	Measured and Calculated Values		Units	Experimental Results				
				Exp. Numbers				
				1	2	3	4	5
1	Heads (water levels in piezometers connected at points 1 ... 6) $H_i = z_i + p_i/\rho g$	H_1	cm					
		H_2	cm					
		H_3	cm					
		H_4	cm					
		H_5	cm					
		H_6	cm					
2	The volume of filtered water W		cm^3					
3	Filtering duration time t		s					
4	Exceeding points 1...6 of connecting piezometers over the reference plane (geometric heights) z_i	z_1	cm					
		z_2	cm					
		z_3	cm					
		z_4	cm					
		z_5	cm					
		z_6	cm					
5	Water temperature τ		$°C$					
6	Filtration flow rate $Q=W/t$		cm^3/s					
7	Filtration velocity $\upsilon = Q/S$		cm /s					
8	Head loss $h_{i-i+1} = H_i - H_{i+1}$	$h_{1\text{-}2}$	cm					
		$h_{2\text{-}3}$	cm					
		$h_{3\text{-}4}$	cm					
		$h_{4\text{-}5}$	cm					
		$h_{5\text{-}6}$	cm					
9	Head gradient $J_{i-i+1} = h_{i-i+1}/l$	$J_{1\text{-}2}$	–					
		$J_{2\text{-}3}$	–					
		$J_{3\text{-}4}$	–					
		$J_{4\text{-}5}$	–					
		$J_{5\text{-}6}$	–					
10	Filtration coefficient $k_{\tau_{i-i+1}} = \frac{\upsilon}{J_{i-i+1}}$	$k_{\tau 1\text{-}2}$	cm/s					
		$k_{\tau 2\text{-}3}$	cm/s					
		$k_{\tau 3\text{-}4}$	cm/s					
		$k_{\tau 4\text{-}5}$	cm/s					
		$k_{\tau 5\text{-}6}$	cm/s					
11	Temperature correction $\Delta\tau = 0{,}7{+}0{,}03\,\tau\,℃$		–					
12	Filtration coefficient at a temperature of 10°C $k_{10_{i-i+1}} = \frac{k_{\tau_{i-i+1}}}{\Delta\tau}$	$k_{10\ 1\text{-}2}$	cm/s					
		$k_{10\ 2\text{-}3}$	cm/s					
		$k_{10\ 3\text{-}4}$	cm/s					
		$k_{10\ 4\text{-}5}$	cm/s					
		$k_{10\ 5\text{-}6}$	cm/s					