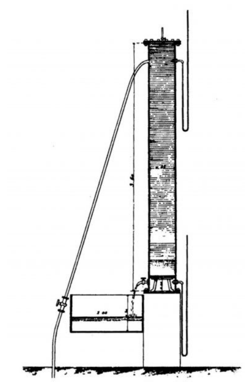
Darcy at home

Manual

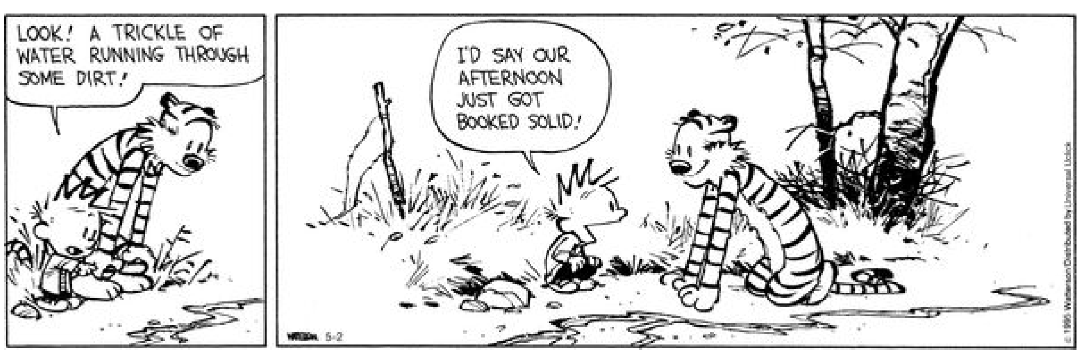
Nick van de Giesen, TU Delft, April 2020 (n.c.vandegiesen@tudelft.nl)

The objective of building and running this lab experiment is to determine two central properties of water carrying layers, the drainable porosity and the hydraulic conductivity. In normal times, this experiment would be run on campus with one hundred identical set-ups but due to the fact that the campus is closed, we need to run this at home. This means you will have to build the set-up yourself, which will appeal to some of your more basic engineering skills. The instruction consists of three parts: 1 Building the experimental set-up, 2 Running the experiments, 3 Analyzing the results. This last part will be done through a Jupyter Notebook. **The final report consists of a set of photos, an Excel and CSV file, mentioned below, and your Jupyter Notebook.**



The original experiment by Henry Darcy[1]

A statue of Henry Darcy in Dijon[2]



[1] https://journals.openedition.org/dht/1625

[2] Wikimedia: https://upload.wikimedia.org/wikipedia/commons/thumb/0/00/Dijon_-_parc_Darcy_-_buste_Darcy.JPG/205px-Dijon_-_parc_Darcy_-_buste_Darcy.JPG

Darcy at home, Part 1: Building the experimental set-up

1.1 Brief overview

There are probably many ways to build a set-up that has the same functionality as the one built here. Feel free to change things as long as we have the following in place in the end.

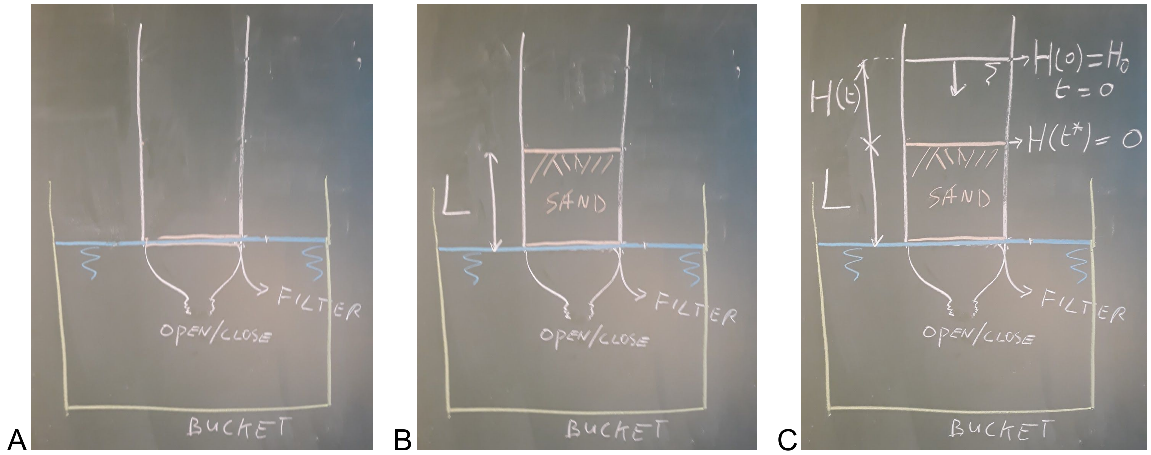


Figure 1 A,B,C: Schematic set-up and experiment

Figure A shows the basic set-up, being a cut open plastic bottle, a filter that lets through water but not sand, suspended at the level of the filter in a bucket, or something similar in which you can control the water level by simply adding or removing water. The filter is typically a piece of cloth but check that it lets through water easily, as not all cloth does.

Just to have an idea about the next steps, there are Figures B and C. B shows the same set-up but now with a layer of sand on top of the filter. The experiment will measure two properties of the sand layer, namely the drainable porosity, μ or *mu* (-), and the saturated hydraulic conductivity, K (m/s). With the set-up in picture B, but with the cap screwed back on the bottle, you can measure μ. In picture C (right) you see the final set-up with which to measure K by observing the speed with which a layer of water passes through the sand.

1.2 Building set-up

Again, there are many ways of building this but the following materials were chosen as they seem to be readily obtainable almost anywhere.

Figure 2: Materials

The materials used here are two plastic bottles of the same size and shape. You want the profile to be regular, preferably cylindrical, and definitely straight (no bulges etc.). Clockwise we then see the sand to be used in the experiment, some stones or gravel (you need much less than the amount shown here), a piece of cloth that lets water through easily (test!), a ruler drawn or printed on paper, scissors, ruler, glue, knife, and some string. In addition, you need a water reservoir or tank, like a bucket, or kitchen sink, or tub, or anything else that will fit the bottle easily. **Regarding the sand**, we will have a thin layer so don't use very coarse sand if you have any choice at all because the water would run through too fast to take good measurements.

Step 1*: *Cut the bottles as shown. One bottle will be the main part of the actual set-up. Cut off the bottom. Keep the bottom as it will be useful later. The second bottle will be cut in three parts. First cut of the top and cut the rim of the top. Make the cut just a few millimeters beyond where the neck starts to narrow. This part looks like a funnel and will hold the cloth and will be placed snugly in the neck of the first bottle to hold the filter in place. The rest serves as a measuring cylinder by simply glueing a paper ruler on the side of the bottle. Make sure the zero of the ruler coincides with the bottom of the cylinder. If the bottom is (very) irregular try to eyeball it in such a way that the equivalent at the start of the regular section is correct. Measure and write down the diameter of the bottle, as this is needed in Part 3.

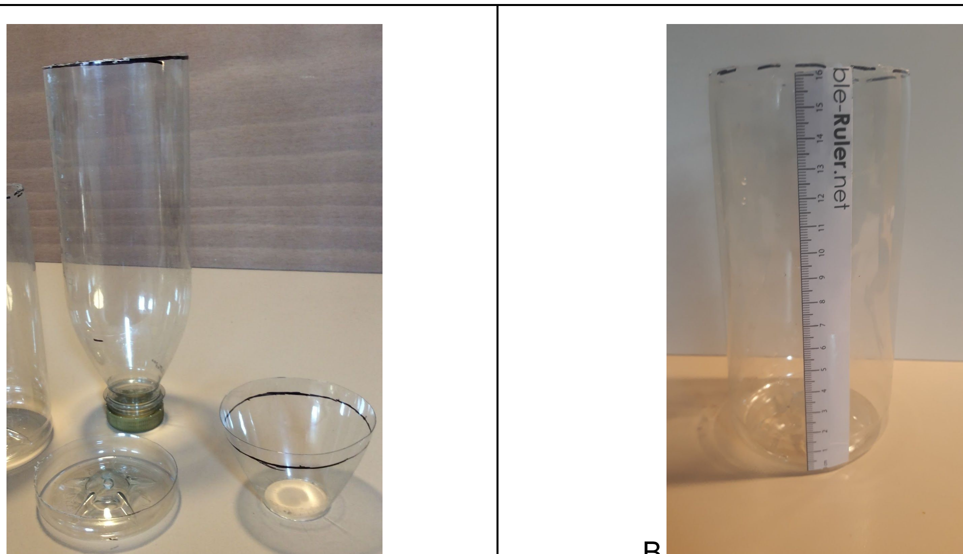
A  B

Figure 3 A,B: A: the two plastic bottles cut. B: the bottle without top can be used as a measuring cylinder by adding a paper ruler. Make sure the zero of the ruler is correct.

Step 2: Building the filter is a bit tricky. One could just span the cloth over the funnel piece but because it has to support a sand column, you want some mechanical support. Again, there are many options, from Lego to 3D printed supports. Here, the choice was some pebbles kept in place with glue (Fig. 4A), also because it adds weight to the set-up, which makes it easier to keep everything in place later on. This can be a bit challenging so be patient. The cloth was then glued to the edge while keeping it taut (Fig. 4B. The filter was then placed in the bottle from which the bottom was cut off (Fig. 4C). Some small gaps between the filter and the bottle walls were filled with some super glue and sand. The shape of the bottle is now often not cylindrical anymore. By putting the bottom back in, upside down, the shape becomes cylindrical again. Because at the next step, air has to flow in and out freely, better make a hole in this bottom.

A

B

C

Figure 4 A,B,C: Building and placing the filter. A: Putting and glueing the pebbles in place. B: Glue the cloth in place by pulling it taught and using super glue. C: Placing the filter in the bottle and filling any gaps with sand and super glue.

Step 3: Installing the set-up will depend a lot on the material at hand and the water tank you are using. In this case, a few strings were used. One string, attached to the neck of the bottle, controlled the exact height of the bottle. The second string was wrapped around the bottle and fixed with some tape (or glue) and fixed in such a way that the set-up would not move left, right, or forward. You can tie the string to anything sufficiently heavy. Here, some eyes were screwed into the plank on which the whole set up is placed. This construction is a bit like a 'tensegrity' construction, in which it helps to fix the ropes with some tape or glue, or have a helping hand. Whichever way you finish your set-up, it is important not to end up with air in the filter. Probably the easiest way to ensure there are **no air bubbles** in your filter is to first fill the set-up under water, let all air escape upwards, then fix the cap back on and have a good layer of water above the filter while you go about the installation.

Finally, take off the cap and adjust the water level such that it is one or two millimeters above the filter and fix a ruler to the front with some clear tape. **Take a picture** and name it #######_set_up.jpg, with your student number instead of '#######'.

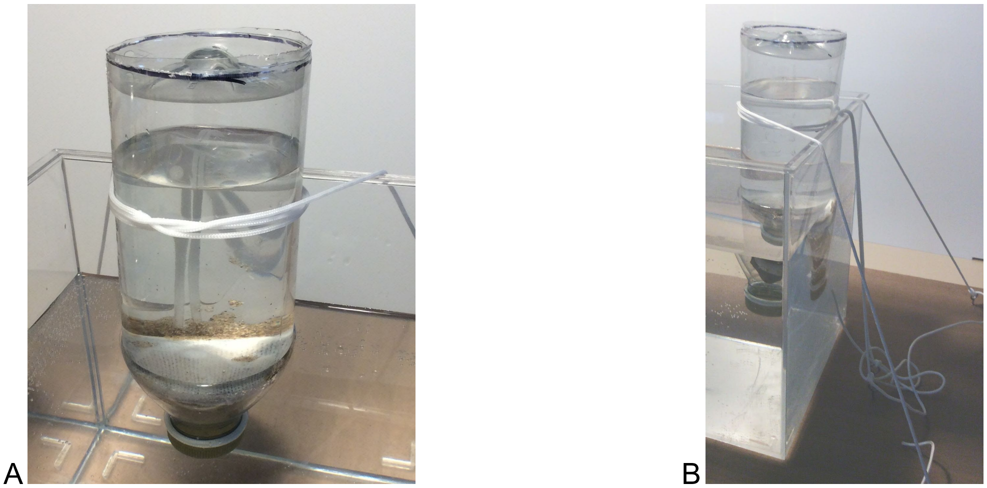


Figure 5 A,B: Fixing the set-up in the tank. Note that the cap is on and that there is a layer of water in the set-up, which helps to keep air from entering the filter.

Step 4: Install a smartphone or camera is another part that can be solved in many different ways. Here, the camera was simply tie-wrapped to a piece of carton that was put on top of the tank. You don't need the camera for the first experiment, which is the determination of the drainable porosity, μ or *mu* (-), but you need it for the dynamic measurement of the hydraulic conductivity, *K*, so we suggest you do the drainable porosity measurement first. The main things to keep in mind is that a) the camera should not get wet or fall into the water unless it is an underwater camera, and b) it should have a clear and focused view of the water level, including the ruler.

Figure 6: Complete set-up with camera.

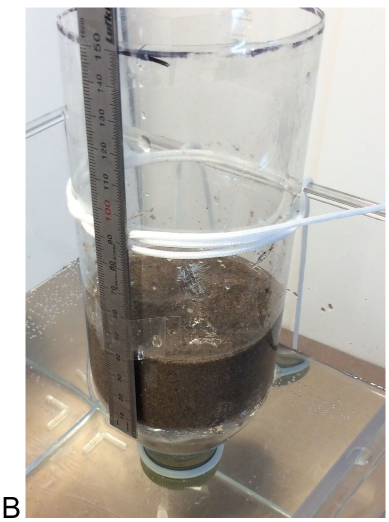
Darcy at home, Part 2: Running the experiment

2.1 Measuring drainable porosity

Step 1: Remove the cap from the bottle so that the water level inside and outside the set-up are the same. Make sure the water level is just 1-2 mm above the filter in the bottle. Remove some water if needed but make sure no air enters the filter as it will be very difficult to remove at this point.

Step 2: Add a layer of 4cm-5cm of (dry) sand. The sand will wet up from the bottom because the water will be sucked up through capillary action. Wait a little until there is no appreciable water movement upwards. Make sure the surface is as even by using a spoon the move sand around as needed. Carefully measure and write down the height of the sand layer, which is the critical parameter *L*, the length of the column. **Put the cap back on**.

A

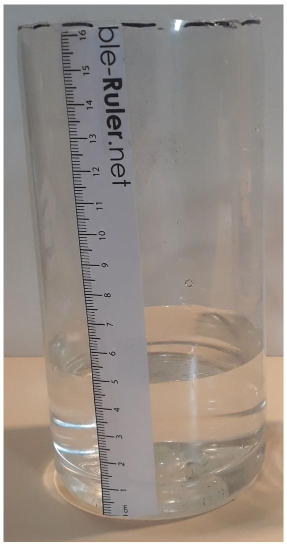


B

Figure 7 A,B: A just before measurement (Step 2), B after adding water, the water is right at the surface of the soil column (Step 3).

Step 3: Now, some water needs to be added to the set-up in order to saturate the sample. To measure how much water this is, first put sufficient water in the measuring cylinder and write down the starting level of the water as *mu_wet1*. This level will need to be entered into the Jupyter Notebook later on. Now slowly and carefully pour water from the measuring cylinder onto the sand in the column while avoiding splashing. You could, for example, hold a bent spoon just above the surface on which you can pour the water to avoid splashing. Continue to pour slowly until the sand is completely saturated and the water just stands at the surface of the sand. Now write down the final water level in the measuring cylinder as *mu_wet2*. Because measuring cylinder and set-up have the same cross-section, one can simply use lengths. **Take a picture** of the saturated sand and name it #######_wet_mu.jpg, with your student number instead of '#######'. The difference between *mu_wet2* and *mu_wet1* is the amount used to saturate the sand.

Step 4: It is likely that the capillary action made the sand very wet and, thereby, the amount of air left in the sample very small. To see what the total porosity is of dry sand, first pour a glass of water in the measuring cylinder and note the water height as *mu_dry1*. Now add a layer of 4cm-6cm dry sand in the cylinder and measure and note the height of the sand carefully as *L_dry* (eventhough by now the sand is wet…). Make sure no air is trapped in the sand sample, you can stir and let the sand settle if need be. Now measure the water height and note it down as *mu_dry2*. **Take a picture** and name it #######_dry_mu.jpg, with your student number instead of '#######'.

A


B


Figure 8 A,B: A: One cup of water in cylinder ("mu_dry1"). B: Water level after adding dry sand. Tap the cylinder to consolidate the sand ("L_dry" and "mu_dry2").

You should now have the following observation table (please fill in your own measurements and use correct units in the Jupyter Notebook):

Parameter	**Measurement**
L_wet	40 mm
mu_wet1	73 mm
mu_wet2	68 mm
L_dry	54 mm
mu_dry1	49 mm
mu_dry2	84 mm
Bottle diameter	81 mm

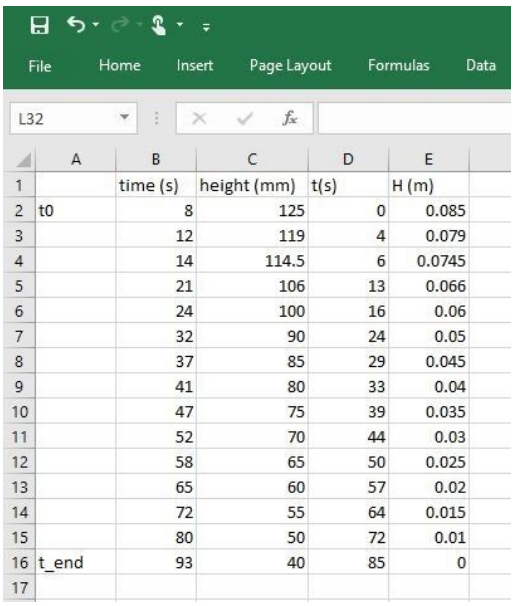
2.2 Measuring hydraulic conductivity

Step 1: First, make sure the cap is still screwed on. Now slowly fill the bottle to close to the top without splashing or eroding the sand. Turn on the camera. Smoothly and rapidly remove the cap. Let the water go down and pay special attention to the moment that the water is just at the surface of the soil column, perhaps marking it with a sound for easy reviewing. Note that if the tank is small with respect to the amount of water flowing in (=appreciable rise in level due to water coming from set-up), try to scoop out some water during the experiment such that the water level in the tank remains more or less the same.

Step 2: Replay the video and read the time and water height. Make sure the start and end are well marked. Add about ten to fifteen points in between. Make of each measurement point a screenshot and name it #######_K0.jpg, with your student number instead of '#######', for the first measurement at t=0, and then continue to number through the screenshots, like #######_K1.jpg, #######_K2.jpg, etc. until the final one called #######_Kend.jpg, each time with your student number instead of '#######'.

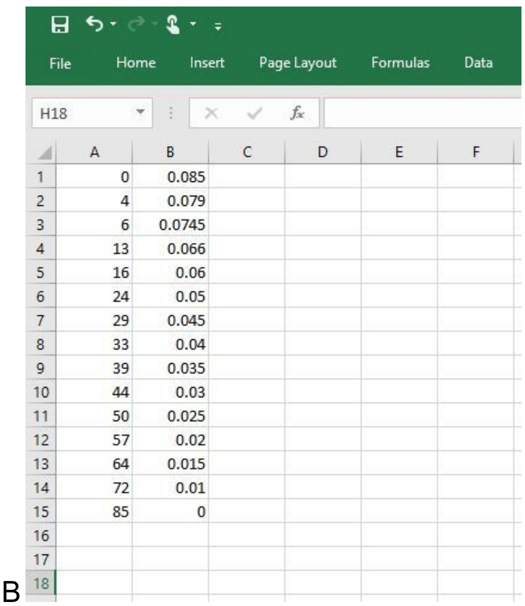
Figure 9: Sample screenshot of measurement point. Both time and water level with ruler have to be in the picture.

Step 3: Enter the measurement points in an Excel fil. First enter the raw data in two columns, and then subtract t_0 from the times and H_{end} from the water heights, as in the example below. Make sure H is in meters in the new column. Now copy and paste only the values, without headers in a second sheet, as shown below. Save just this sheet as a csv file and name it #######_H.csv, with your student number instead of '#######'. Save the complete spreadsheet as #######_H.xls, with your student number instead of '#######'. Also take a screenshot of the #######_H.csv file and save this as #######.jpg with your student number instead of '#######'.



	A	B	C	D	E
1		time (s)	height (mm)	t(s)	H (m)
2	t0	8	125	0	0.085
3		12	119	4	0.079
4		14	114.5	6	0.0745
5		21	106	13	0.066
6		24	100	16	0.06
7		32	90	24	0.05
8		37	85	29	0.045
9		41	80	33	0.04
10		47	75	39	0.035
11		52	70	44	0.03
12		58	65	50	0.025
13		65	60	57	0.02
14		72	55	64	0.015
15		80	50	72	0.01
16	t_end	93	40	85	0
17					

A



	A	B	C	D	E	F
1	0	0.085				
2	4	0.079				
3	6	0.0745				
4	13	0.066				
5	16	0.06				
6	24	0.05				
7	29	0.045				
8	33	0.04				
9	39	0.035				
10	44	0.03				
11	50	0.025				
12	57	0.02				
13	64	0.015				
14	72	0.01				
15	85	0				
16						
17						
18						

B

Figure 10 A,B: A the Excel sheet with raw data and adjusted t and H. B shows just the data as values (not formulas) in a separate sheet.

2.3 Wrapping up

Below, replace '#######' with your student number.
Collect all files in one directory and name the directory #######_CTB2410_GW. Put all outcomes in this directory. This should now contain:

#######_set_up.jpg
#######_wet_mu.jpg
#######_dry_mu.jpg
#######_K0.jpg
#######_K1.jpg
…
#######_Kend.jpg
#######_H.csv
#######_H.xls
#######_H.jpg

Now add the zipped file ‘Darcy_at_Home.zip’ from Brightspace into this directory, open the Jupyter Notebook, enter the data requested and do the analysis. It is assumed you are familiar with Python/Jupyter Notebooks, otherwise see: https://youtu.be/fnl6N_F7TvI (Mark Bakker intro).

Once all is done and you are happy with the results, zip the complete directory, name it #######_CTB2410_GW.zip and upload it to Brightspace under the correct Assignment. Please try to keep the file size reasonable (<20M), if need be by shrinking and/or cropping individual pictures while keeping them clearly readable.