51
Preliminary report I Претходно саопштење
DOI 10.7251/STP2215530P
ISSN 2566-4484

Petar Praštalo, University of Banja Luka, petar.prastalo@aggf.unibl.org
Ljiljana Brajović, University of Belgrade, brajovic@grf.bg.ac.rs
Dušan Prodanović, University of Belgrade, dprodanovic@grf.bg.ac.rs

USING OF LOW COST MOISTURE SENSORS IN LABORATORY EXPERIMENTS

Abstract

Soil moisture is one of crucial parameters in modeling and analysis of groundwater flow. Measurement of soil water dynamics improves the understanding of processes and is vital for good groundwater flow model calibration. Determining soil moisture change during time by laboratory methods, as an integral part of practical classes, requires significant material and financial resources. Nowadays, relatively cheap sensors for measuring soil moisture are available. They could be combined with affordable data loggers to speed up the measurement procedure and to reduce cost price. In this paper, the possibility of using these sensors for measuring soil moisture and their usage for the educational experimental exercises in a field of hydraulic engineering was investigated. The paper first presents the procedure of sensor calibration for four different sensors used in two types of soil, and then their usage in a simple hydraulic engineering experiment.

Keywords: Soil moisture, sensors, measurement, hydraulic engineering.

КОРИШЋЕЊЕ ЈЕФТИНИХ СЕНЗОРА ВЛАГЕ У ЛАБОРАТОРИЈСКИМ ЕКСПЕРИМЕНТИМА

Сажетак

Влажност тла је један од важнијих параметара у моделирању и анализи подземних вода. Познавање динамике промјене влажности тла је кључно у калибрацији симулационих модела. Одређивање влажности тла лабораторијским методама, као саставни дио практичне наставе, захтијева значајна материјала и финансијска средства. Данас су доступни релативно јефтини сензори за мјерење влажности тла, који комбиновани са широко распрострањеним дата логерима могу да убрзају поступак мјерења и да смање трошкове опреме. У овом раду истражена је могућност коришћења ових сензора за мјерење влажности тла и њихова примјена у експерименталном дијелу наставе хидротехнике. У раду је прво приказан поступак калибрације четири различита сензора коришћењем двије врсте тла и могућност њиховог коришћења за извођење једноставних експеримената.

Кључне ријечи: Влажност тла, сензори, мјерење, хидротехника.

1. INTRODUCTION

Soil moisture is the most important quantity in the study of soil in Civil Engineering and Agriculture. All soils are water permeable, because water can move through the space of interconnected pores between solid particles [1]. Determination of soil moisture content can be done with various measuring methods, devices and sensors. The choice of a method is based on its cost and the required accuracy. Drying and measuring the soil samples is a standard method for measuring soil moisture in the laboratory, but not for in situ measurements [2] nor can be used for measurement of soil moisture dynamic. Fortunately, the accuracy of moisture sensors is increasing, while their prices are decreasing [3]. In addition, a fact that their cost is low, is a good reason for their use in creating the laboratory experiments for students' practical work, as a part of teaching process in a field of hydraulic engineering at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka.

2. METHODOLOGY

When choosing sensors for measuring soil moisture, it is convenient that they can be connected to the Arduino platform. The Arduino is an open source platform, based on the ease of use of hardware and software. *Arduino UNO* boards can read signals from a large number of sensors. In addition, *Arduino UNO* boards have the ability to send output data to various devices, so that the data can be displayed on the screen or acquired in file on the computer, etc. [4]. With addition of solid state memory and real-time clock, the Arduino platform can be used to build the cheap data logger system.
In this research, Arduino board was used to read the analog output signals (voltages) from moisture sensors, while the results were displayed on a computer. Capacitive and resistive type moisture sensors were used for the testing.
In Figure 1 the Arduino board and the four sensors used to measure soil moisture are presented.

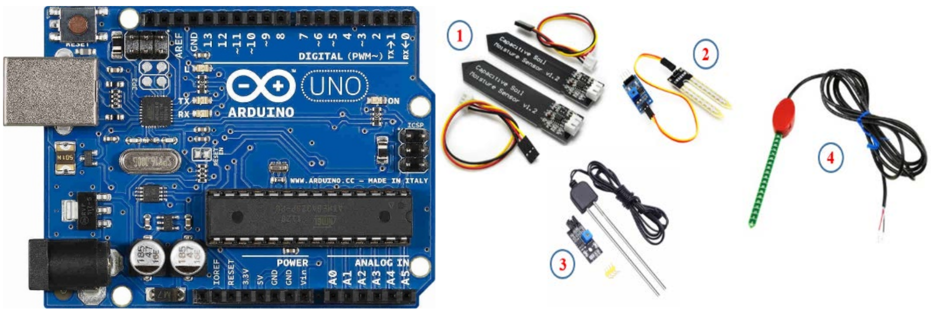

Figure 1. *Arduino UNO board (left)[7], and soil moisture sensors (right)*

Capacitive type soil moisture sensors usually have a structure of coplanar capacitors. When they are inserted in a soil, the soil moisture content influences their capacitance and by measuring the capacitance the moisture could be determined [3]. Resistant soil moisture sensors determine the amount of moisture in the soil by measuring the electrical resistance between two metal strips that are inserted into the soil (metal strips have to be in direct contact with wet soil) and whose moisture is being measured [5]. In order to convert these capacitance or resistor values in an appropriate voltage output signal these sensors are connected to appropriate electrical circuits.
The principle of operation itself implies that the sensors are previously calibrated. Calibration means the formation of a relationship between the output signal and soil moisture. This dependence serves to determine the soil moisture based on the measured voltage. In working with these sensors, a supply voltage of 5V was used, while the output voltage was measured using an Arduino board and a computer, and then was converted into soil moisture using the calibration curves.
Water content or soil moisture *w*, is defined as the ratio between the mass of water m_w and the mass of dry soil m_d, usually expressed as a percentage, and can be represented by the expression:

$$w = \frac{m_w}{m_d} = \frac{(m_s - m_d)}{m_d}\ (x100)\ [\%] \qquad (1)$$

Where the quantities represent: *w* – soil moisture, m_s – mass of wet soil, m_w – mass of water, m_d – mass of dry soil.

Instead of expressing soil moisture by its standard definition given in equation (1), the volume content of water could be used. It is denoted with (and defined by equation (2) as follows [3]:

$$\Theta = \left(\frac{m_s - m_d}{m_d}\right) \cdot \frac{\rho_{d,s}}{\rho_w} \quad \left[\frac{cm^3}{cm^3}\right] \tag{2}$$

Where $\rho_{d,s}$ represents density of dry soil and ρ_w *the* density of water.

3. CALIBRATION OF SOIL MOISTURE SENSORS

Calibration is a common procedure used to form a functional relationship between output signal (voltage) and soil moisture and in such a way form the calibration curve. This dependence serves to determine the soil moisture based on the known voltage. This function is usually linear, or a polynomial to a certain degree. During this test, the volume content of water was determined based on equation (2).

For the calibration procedure in this research, the following equipment was required:

- Sensors to be tested (in this case 2 capacitive and 2 resistive types soil moisture sensors),
- *Arduino UNO* board (hardware),
- Graduated container,
- Water measuring cup,
- Scale with high precision (precision 10^{-4} g),
- Furnace for drying soil samples.

Two soil samples were used, namely the gravel sample (non-homogeneous) and the sand sample (homogeneous). The gravel sample had a grain size of 0 - 16 mm, while the sand had a grain size of 0 - 2 mm. The granulometric curves of soil samples are presented in Figure 2.

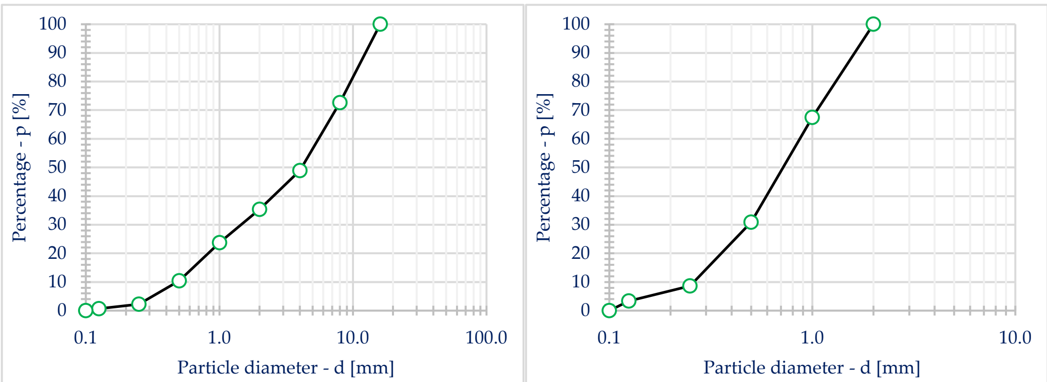

Figure 2. *Granulometric curve the gravel (left) and sand (right)*

The calibration procedure included the following:

- After taking a soil sample, it is dried in an oven at a temperature of 105°C until achieving a constant mass. Because the water evaporated from the sample and the sample is completely dry, so its soil moisture is zero.
- Dried the sample, it is necessary to cool it to room temperature of about 20°C, and then pour it into a graduated container (special care is needed to prevent the moisture from surrounding air to enter the sample).
- Mass of the dried sample together with the mass of the graduated container was measured. Because the mass of empty graduated container is known, by subtracting those two masses, the mass of the dry sample soil is obtained.
- In the soil sample formed in this way, a sensor is installed and the signals are read on the computer screen.
- Then a certain amount (mass) of water is added and measured together with the mass of the sample and the mass of the graduated container.
- Is necessary to homogenize the sample, by manual mixing of the sample until complete homogeneity, and output signal stabilization.
- In performed tests, the volume of water added to the sample was about 20 ml (this was 5% water content).
- The output voltage was registered on the computer.
- Next, the procedure from step 5: adding water to the sample, measuring the mass of the wet sample, and reading the output voltage, for several soil moisture content.

The soil samples after the drying process, and removing water from the soil and presented in Figure 3.

Figure 3. *Samples used for experiment, gravel (left) and sand (right)*

The amount of water added to the sample depends on the mass of the sample used during the test. In conducting this experiment, the goal was to determine 9 to 10 measuring points, so that the soil moisture reaches about 30%.

The sensors are numbered, during calibration for easier comparison of results, as follows:

- *Capacitive Soil Moisture Sensor (DF Robot Electronics)* - Sensor 1,
- *Resistive Hygrometer Detection Module (ShenZhen HaiWang Sensor Co.LTD)* - Sensor 2,
- *Resistive Soil Moisture Sensor (Think Robotics)* - Sensor 3,
- *Capacitive Soil Moisture Sensor Vegetronix VH400 (Vegetronix)* - Sensor 4

4. DESCRIPTION OF THE EXPERIMENT

After the calibration of the sensors, the experiment was started. The experimental setup consists of two containers connected by pipes. One container contains a dry soil sample with two inserted sensors of the same type (*Vegetronix VH400*), and the second one contains water. For the achieved piezometric head difference (H=40cm), it was possible for water to flow towards the sample. After the water passes through the sample and rises above the surfaces of the soil sample, the water container is lowered abruptly so that the direction of flow is reversed with the same piezometric head difference. Soil moisture changes were measured by the sensors during this experiment. To better illustrate the experimental setup, the Figure 4 shows the phases of the experiment.

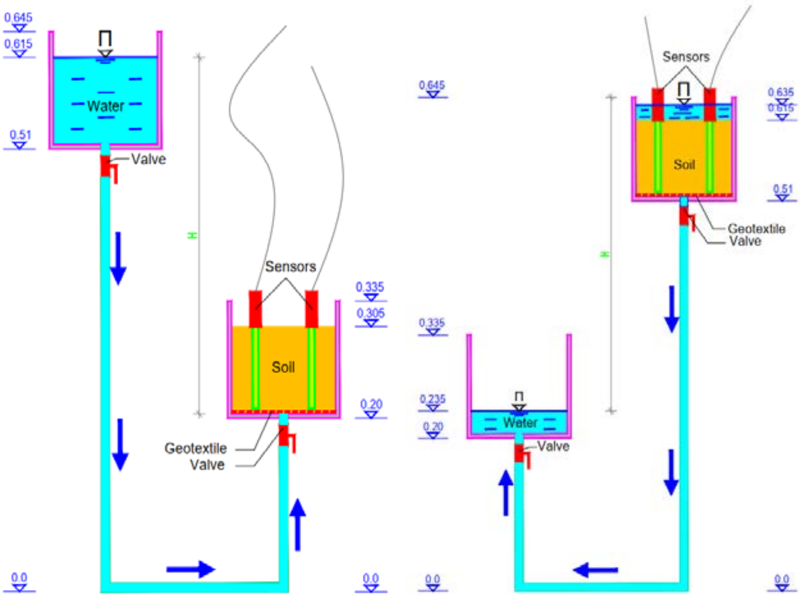

Figure 4. *Experiment setup and its phases A- raising the wet front in a sample (left) and phase B - lowering the wet front in a sample (right)*

The previously presented experiment is similar to the Darcy apparatus, but the main difference is that it measures the change in moisture of the soil in real time using sensors. During the experiment, a constant amount (1.5 liters) or water volume is used.

5. SENSOR CALIBRATION RESULTS

The calibration of sensors included all previously described procedures in Section 3. The calibrated curves were determined as a dependence of the volumetric moisture content versus $1/U$ ratio i.e. the inverse of Output voltage U. They are presented for all investigated sensors in Table 1, for the gravel sample. In the table in a third column the root mean square deviation value (RMSE) is presented too. In Table 2 are presented calibrated curves for sand samples.

Table 1.Dependences of the output voltage and water volume content for the tested sensors in the gravel sample

Sensor	Equation	RMSE	No. Eq.
Sensor 1	$\Theta = 2.0543 \cdot \frac{1}{U} - 0.386$	0.080	(3)
Sensor 2	$\Theta = 1.2769 \cdot \frac{1}{U} - 0.2069$	0.071	(4)
Sensor 3	$\Theta = -6.2496 \cdot \frac{1}{U^2} + 5.0144 \cdot \frac{1}{U} - 0.7399$	0.037	(5)
Sensor 4	$\Theta = 0.077 \cdot \frac{1}{U^2} - 0.3316 \cdot \frac{1}{U} + 0.3777$	0.012	(6)

Table 2.Obtained dependences of the output voltage and water volume content for the tested sensors in the sand sample

Sensor	Equation	RMSE	No. Eq.
Sensor 1	$\Theta = 0.9556 \cdot \frac{1}{U} - 0.1657$	0.031	(7)
Sensor 2	$\Theta = -11.404 \cdot \frac{1}{U^2} + 7.4953 \cdot \frac{1}{U} - 0.987$	0.164	(8)
Sensor 3	$\Theta = 1.2095 \cdot \frac{1}{U} - 0.1752$	0.020	(9)
Sensor 4	$\Theta = 0.0808 \cdot \frac{1}{U^2} - 0.3655 \cdot \frac{1}{U} + 0.4833$	0.018	(10)

Functional dependencies are calculated with a criteria to obtain the highest possible coefficient of determination. The coefficient of determination for all tested sensors is greater than 0.9. The graphs in Figures 5, 6, 7 and 8 show the calibration curves that were formed after testing the sensors.

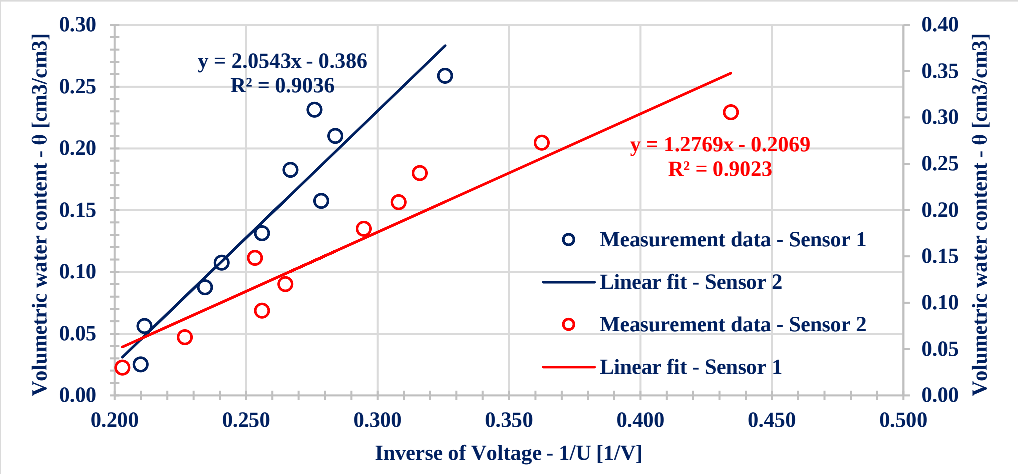

Figure 5. *Dependence between water content and inverse voltage for Sensor 1 and Sensor 2 in the gravel soil*

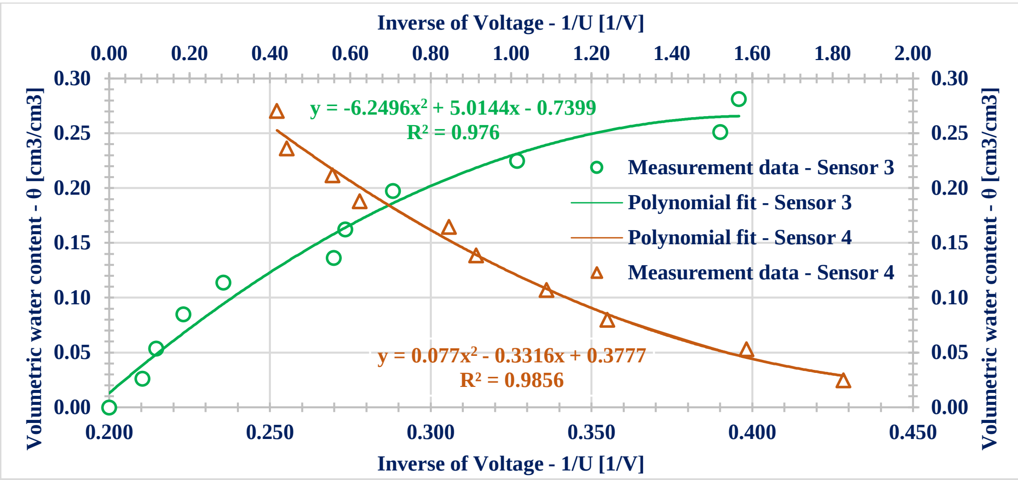

Figure 6. *Dependence between water content and inverse voltage for Sensor 3 and Sensor 4 in the gravel soil*

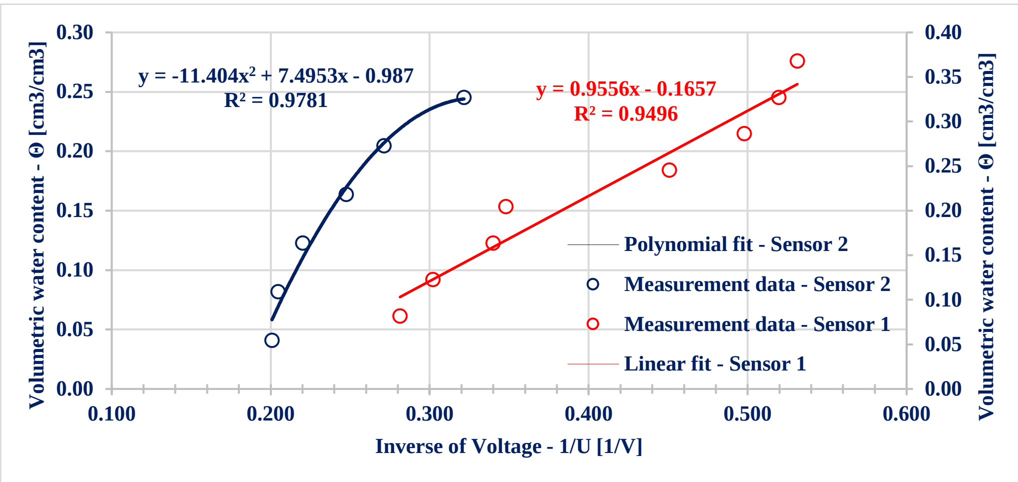

Figure 7. *Dependence between water content and inverse voltage for Sensor 1 and Sensor 2 in the sand soil*

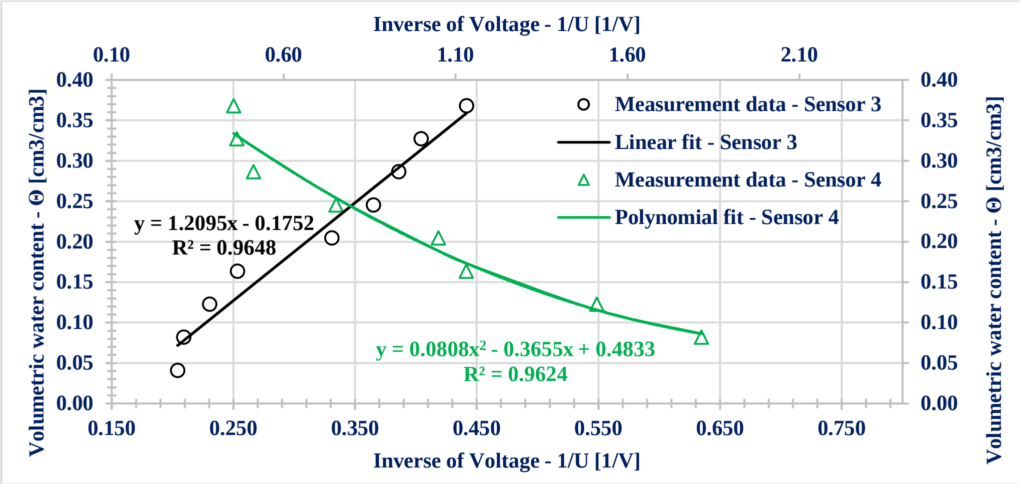

Figure 8. *Dependence between water content and inverse voltage for Sensor 3 and Sensor 4 in the sand soil*

6. EXPERIMENTAL RESULTS

After calibrating the sensors, the previously described experiment was established and performed. Two *Vegetronix VH400* sensors (Sensor 4a and Sensor 4b) were used to conduct the experiment. This type of moisture sensor is often used in agriculture, as it is described in papers [6], [8].

The final result of the experiment is measuring the change in soil moisture in real time, during the movement of the wet front through the soil sample. Soil moisture values were determined on the basis of calibration curves. In Figure 9 the soil moisture change during the experiment for gravel sample is presented. The photograph of a gravel soil sample during rising the wet front is presented in Fig. 10.

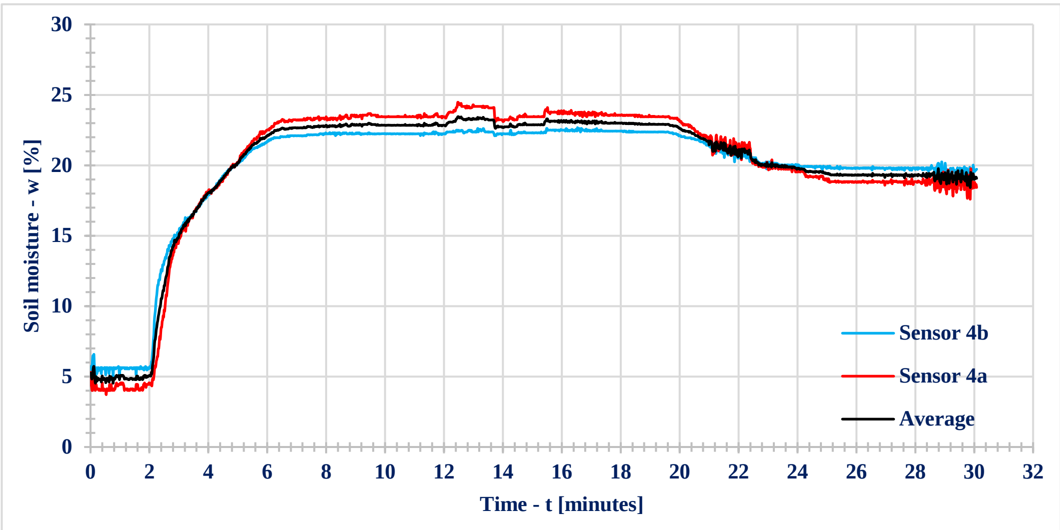

Figure 9. *Soil moisture measurement results during the experiment on the gravel soil*

Based on the obtained soil moisture measurements during the experiment with the two sensors (denoted as 4a and 4b), a certain difference in measured values can be noticed, but the error was not more than 1%. At the end of the experiment, both sensors showed the same value of soil moisture, which was about 19%.

Figure 10. *Phase of the experiment during the movement of the wet front*

The experiment was repeated with the sand sample. The results are shown in Figure 11.

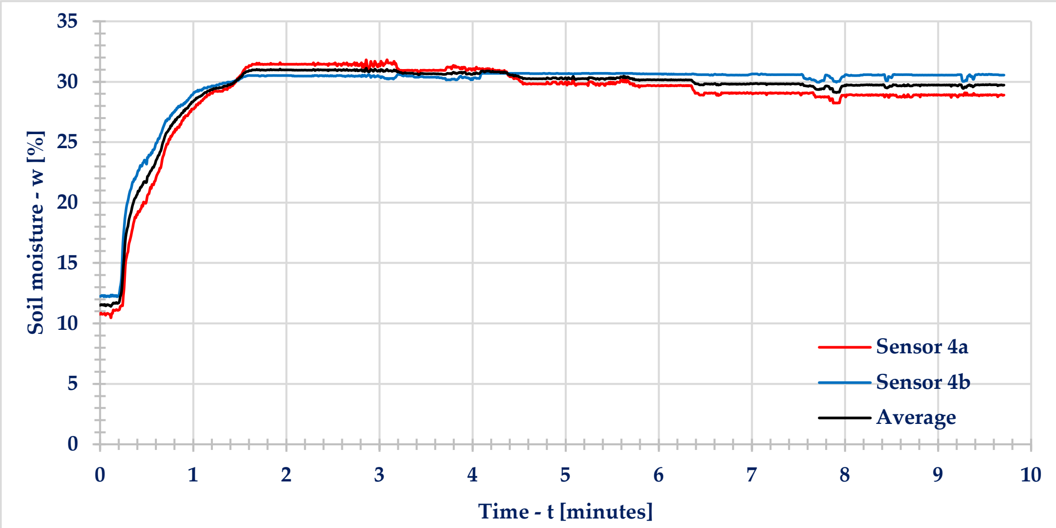

Figure 11. *Soil moisture measurement results during the experiment on the sand soil*

Comparing the experiments with two types of sand samples, it was clear that the wet front moved much faster through the sand sample than in the gravel sample. After lowering the head water elevation, in the second phase of the experiment, the soil moisture of the sample remained fairly constant even after water came out of the soil sample. Because it takes a time for the soil moisture to significantly change, the experiment was stopped at a soil moisture values about 30%.
Figure 12 shows the movement of the wet front during the experiment on sand soil.

Figure 12. *Phase of the experiment during the movement of the wet front*

7. DISCUSSION OF RESULTS

In this paper, soil moisture sensors were examined, their calibration was made on the basis of known sample's soil moisture, and the possibilities of their use in the teaching process of hydraulic engineering was investigated. Calibration curves between soil moisture and sensor output signal were formed for two types of soil moisture sensors, resistive and capacitive. Used sensors were relatively cheap, with uncompensated response for different types of soils and clay content. Because of that, each sensor had to be individually calibrated with used soil.

The obtained calibration curves for non-homogeneous and homogeneous soil samples (Figures 5 to 8), for used range of soil moistures (from 0 – 35%) were linear and quadratic polynomial functions (to be more precise, the full-range output of all sensors is quadratic, but certain sensors in limited range of soil moisture can be considered as with linear output). A high coefficient of determination was obtained (>0.9), for all dependencies during sensor testing. It was noticed that the capacitive sensors are more accurate than resistive and have a lower value of the root mean square error, which can be seen in Table 1 and 2.

An experiment for investigating the change of soil moisture of the sample during the movement of the wet front in the sample was performed using two capacitive *Vegetronix VH400* sensors. The conducted experiment aimed at examining the possibility of using soil moisture sensors in the teaching of Hydraulic Engineering and performing the similar experiments for students' practical work. *Arduino UNO* board is proved to be reliable hardware for testing sensors. Due to its relatively low cost it can be used for connection of different types of sensors during experimental exercises. During the experiments, measured data were transferred directly to the computer, but additional local memory can be added to the Arduino, allowing field measurements.

Based on a large number of researches and the performed calibrations, the noticeable advantage has been given to capacitive sensors, as reliable sensors for measuring soil moisture. Also, among them the *Vegatronix VH400* sensor is mostly recommended to be used for irrigation purposes in agriculture especially for control and regulation of irrigation systems.

The conducted experiment proved a concept that it is possible to have a convenient, relatively simple and low cost way to perform measurements of soil moisture in the teaching process of Hydraulic Engineering. From a practical point of view, it is very simple to measure soil moisture using described capacitive sensors connected to an Arduino board and at the same time it is useful for students to gain practical knowledge about it.

8. CONCLUSION

This work described testing soil moisture sensors, using an *Arduino UNO* board and an *Arduino IDE* software. Two capacitive sensors and two resistive sensors were used for testing. The tests were performed on a gravel and sand sample, according to the procedure previously described in the sensor calibration section.

The formed calibration curves are valid only for the tested soil samples. Also, it is recommended to perform sensor tests with other soil types and to compare them with the formed calibration curves.

It is better that the sample of soil material used for calibration have uniform granulometric composition, in order to achieve the best possible homogeneity of the wet sample after mixing. In this way, a better reading on the sensors is achieved, the output voltage is stable, which is also the manufacturer's recommendation. When reading the sensor output voltage using the *Arduino UNO* program, it is recommended that the sensor should be inserted into the soil to a certain depth in order to read a representative signal value. If the sensor is inserted too deep, a higher than real value of the output signal is observed. The capacitive soil moisture sensor can take some time to equalize and give steady reading and it is necessary to wait approximately one minute after the sensor settles to a given value [3].

With the help of investigated sensors, it is possible to organize practical exercises for the teaching of hydraulic engineering. Capacitive soil moisture sensors can be used for slow time–varying measurements, especially in real time measurement of soil moisture changing processes in a range from 0 to 30%. These relatively inexpensive sensors as well as the *Arduino UNO* board available on the market can give reliable results in such types of the experiments.

LITERATURE

[1] M. Makismović, "Mehanika tla", Univerzitet u Beogradu, Građevinski fakultet Beograd, 1995,

[2] B. Radičević, Đ. Vukić, Đ. Ercegović, M. Oljača, "Mjerenje vlažnosti tla", Poljoprivredna tehnika, broj 4, decembar 2008, str 25 - 36, UDK:336.142,

[3] J. Hrisko, “Capacitive Soil Moisture Sensor Theory, Calibration, and Testing,” no. July, 2020, doi: 10.13140/RG.2.2.36214.83522.

[4] Arduino For Beginners, www.Arduino.com, vol. 4, no. 2, pp. 457–463, 2018,

[5] D. Stanoković, "Fizičko tehnička mjerenja - senzori" Univerzitet u Beogradu, Beograd 1997,

[6] Murtiningrum, Ngadisih, F. A. Rizqi, and M. I. Ulumuddin, “Irrigation volume calculation based on soil wetting pattern in trickle irrigation,” IOP Conf. Ser. Earth Environ. Sci., vol. 365, no. 1, 2019, doi: 10.1088/1755-1315/365/1/012010,

[7] https://www.arduino.cc/en/software,

[8] http://www.cheapvegetablegardener.com/how-to-use-vegetronix-soil-moisture,

[9] https://www.ardumotive.com/soil-hygrometer-module-en.html