International Journal of Engineering & Technology, 7 (4.37) (2018) 79-85

International Journal of Engineering & Technology

Website: Www.Sciencepubco.Com/Index.Php/IJET

Research Paper

Variation of Suction during Wetting of Unsaturated Collapsible Gypseous Soils

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Abstract

Gypseous soils represent as essential soils that exhibit unsaturated behavior that differs completely than their behavior during soaking. Their strength, stiffness, and compressibility are dependent on the degree of saturation.

The soil used in this research is disturbed natural gypseous soil having three different percentages of gypsum; 55, 30 and 18%. Nine model tests were conducted to investigate the variation of suction, settlement and total vertical stress with time, also, to study the effect of wetting on the volume change of unsaturated gypseous soil. The soil container used with inner dimensions of (length 700× width 700× height 600 mm). A square footing with (100 mm) sides was used. Models in loose, medium and dense soils were prepared. Watermark monitor data logger model 900M was used, with automatic data collection device that measures soil suction in kPa. The saturation process involved the complete saturation until the suction sensors readings approach to zero. The saturation process was established by allowing the water to infiltrate through the soil in upward-direction with a steady flow and head of 2 m.

For all soil models, the time needed to reach the zero suction (saturation state) increased with the increase of the initial dry density. The initial value of suction for all soils increased with decreasing of the initial water content. The drop in the readings of suction may be due to the effect of gypsum content on the adsorption of water that leads to the saturation of the sensors surrounding area.

Keywords: *Collapsibility, Gypseous soil, Soaking, Suction, Unsaturated soil, Wetting.*

1. Introduction

The gypseous soil considered as complicated with unpredictable behavior that makes it a problematic soil. Gypseous soils attain high shear strength with very low compressibility at dry state, but a sudden collapsible behavior appears when exposed to water. Gypseous soil intensifies in arid and semi-arid regions. About 20-30% of the total area of Iraq is covered with gypseous soil. In Iraq, it has been recorded that several structures have faced different patterns of cracks and uneven deformations generated by exposing gypseous soil to water. Changes of water content in gypseous soil lead the gypsum which role as cementing agent to dissolute within the soil mass which results in one or combination of three processes, first breaking down of the bonds between soil particles supported by the gypsum followed by the collapse of soil structure and this process occurs almost immediately. The second process is consolidation, while the third is leaching process that appears when the water flow continues through the soil mass. The combination of these processes will cause the soil to settle considerably when loading is applied (Al-Obaidi and Al-Mafragei, 2014). Gypseous soils are distributed in vast areas and various regions of Iraq and other countries. Many foundation failure problems that occur in these soils are associated with percolation of water and dissolution of gypsum. Many attempts were made by several researchers to treat and improve the properties of gypseous soils to decrease the dissolution of gypsum and collapse potential of these soils (Fattah et al., 2012). Soil suction is commonly implied to as the free energy state of soil–water (Edlefsen and Anderson, 1943), which can be measured in terms of its partial vapor pressure.

Total suction has two component: matric suction $(u_a - u_w)$ and osmotic suction (π),

$$\psi = (u_a - u_w) + \pi \tag{1}$$

A change of total suction is generally caused by a change of relative humidity RH in the soil. RH can be reduced due to the presence of a curved water surface produced by capillary phenomenon, i.e., contractile skin (Fredlund and Rahardjo, 1993). Osmotic suction is a function of the number of dissolved salts in the pore fluid and is formulated in terms of pressure, Zhou et al. (2012). Al-Obaidi et al. (2013) during their work on investigating the effect of increasing gypsum content on the total suction estimation for gypsum sand mixture reached to results, which revealed that the gypsum content increases within soil mixture which cause a slight decrease in the value of the measured total suction.

Fattah et al. (2014) concluded that as long as the specimens were saturated, the strength of the sand appeared to increase at the same rate as for an increase in total stress.

For gypseous soil, the researchers studied improvement of engineering properties of the soil or tried to treat it by coating or to add chemical materials to prevent the gypseous soil from exposure to water which leads to the dissolution and breakdown of gypseous particles bonds, Zhang, (2008). Studying unsaturated gypseous soil behavior may lead to more understanding of the gypseous soil problem associated with the unsaturated problem.

This paper aims to model the behavior of gypseous soil in the framework of unsaturated soil mechanics. The work is directed to predict the volume changes associated with the changes in soil suction and present the investigate the effect of initial dry density, initial degree of saturation and gypsum content on suction with time.

2. Materials and Methods

Three different disturbed natural gypseous soils samples were selected in this research, Soil No. I from northern of Samarra city in Salah-Aldine governorate with high gypsum content (55%), Soil No. II from Abu Ghraib district west of Baghdad city with medium gypsum content (30%) and Soil No. III from Abu Ghraib district also with medium gypsum content (18%). To determine the required soil parameters, a soil-testing program was carried out at the Soil Mechanics Laboratory at University of Technology in Baghdad. Routine soil tests were carried out to characterize the soil properties, namely the grain size analysis, (ASTM 422, 2010), specific gravity (ASTM 854, 2010), direct shear test, (ASTM 3080, 2011), and maximum and minimum dry density tests, (ASTM 4253, 2014). The grain size distribution curve is shown in Figures (1) to (3). Distilled water is normally used for specific gravity determination, but Kerosene is recommended instead of distilled water when the soil specimens contain a significant fraction of organic matter or gypsum material. Specific gravity tests showed a decrease in Gs with the increase in gypsum content. This aspect of gypsum soils is important because Gs is directly associated with the unit weight of soils which is essential for all major geotechnical calculations. The mechanical and chemical properties of the soils used are summarized in Tables (1) and (2).

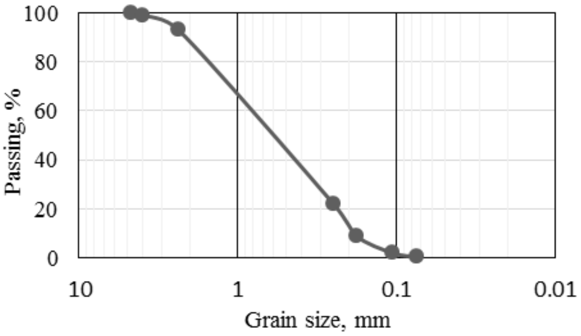

Fig. 1: Grain size distribution of soil No. I with 55% gypsum content.

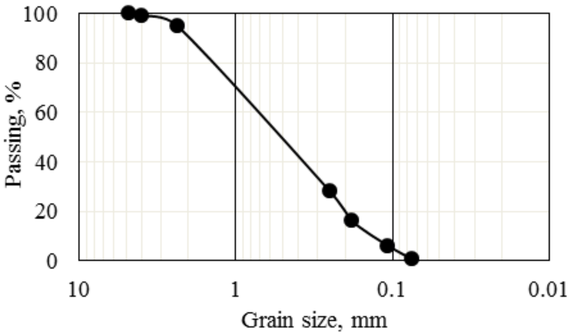

Fig. 2: Grain size distribution of soil No. II with 30% gypsum content.

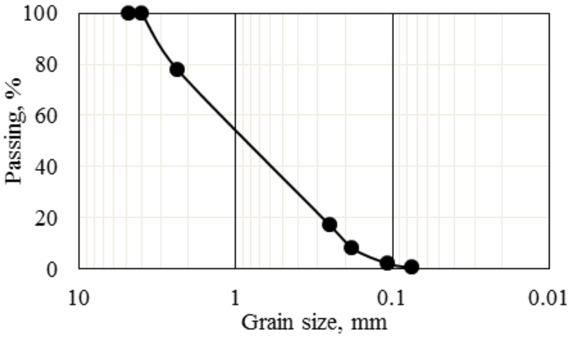

Fig. 3: Grain size distribution of soil No. III with 18% gypsum content.

The gypsum content was calculated according to the procedure recommended by Nashat and Al-Mufty, (2000). In this method, an oven drying of the soil at (45°C) will done until the weight of the sample becomes stable. The sample weight at (45°C) is verified. Then, the sample is dried to (110°C). The gypsum content is calculated according to the following equation:

$$\chi\ (\%) = \left[\frac{\left(W_{45^{\circ}C} - W_{110^{\circ}C}\right)}{W_{45^{\circ}C}}\right] \times 4.778 \times 100 \qquad (2)$$

where: χ = gypsum content (%),
$W_{45^{\circ}C}$ = weight of the sample at (45ºC), and
$W_{110^{\circ}C}$ = weight of the sample at (110 º C).

Table 1: Physical and mechanical properties of the used soils.

Index Property	Soil I	Soil II	Soil III
Gypsum content, %	55	30	18
Specific gravity(Gs)	2.36	2.54	2.61
D_{10} (mm)	0.18	0.13	0.2
D_{30} (mm)	0.31	0.27	0.4
D_{60} (mm)	0.8	0.7	1.15
Coefficient of uniformity (Cu)	4.4	5.4	5.8
Coefficient of curvature (Cc)	0.7	0.8	0.7
Maximum dry unit weight (kN/m^3)	16.8	17.21	17.34
Minimum dry unit weight (kN/m^3)	12	12	12
Soil Classification according to (USCS)*	SP	SP	SP
Friction angle, (ϕ) in degrees	38.1	36.3	36.1
Cohesion (c), in kPa	8	5	3

* USCS: Unified Soil Classification System.

Table 2: Chemical properties of soil.

Chemical properties	Soil I	Soil II	Soil III
Gypsum content %	55	30	18
Total Sulphate content(SO3)%	25.5	13.9	8.4
pH value	8.25	8.31	8.28

Table (3) shows the given name for the 9 model tests; simplified names are used for the explanations of the soil samples that will be dealt within in the experimental work, symbols are used to characterize each soil. In addition, the data of the soil gypsum content, unit weight in the model and degree of saturation are mentioned. Plate (1) shows the manufactured apparatus model

Table 3: Simplified names for soil models in the tests.

Test Name	Gypsum content, %	Dry unit weight, kN/m^3	Degree of saturation, %
A1	55	16.3	5.61
A2	30	16.3	4.80
A3	18	16.3	4.73
B1	55	14.8	4.18
B2	30	14.8	3.72
B3	18	14.8	3.58
C1	55	13.5	3.30
C2	30	13.5	3.00
C3	18	13.5	2.91

Two soil containers were used with inner dimensions of (length 700× width 700× height 600 mm) made as one piece of steel plate with 4 mm thickness.

The axial loading system consists of two base plates that were tied together by four (17 mm) stainless steel bolts at the corners that making the two plates easy to slip along the horizontal direction or fastened at the desired location. A square footing of (100 mm) sides was used; it was made of three layers of plastic glasses each one is (10 mm) thick glued together.

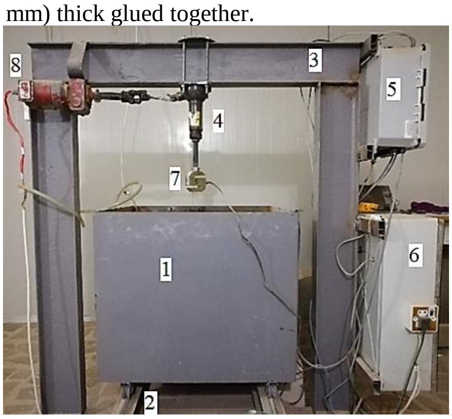

Plate 1: Apparatus model used in tests. (1) Steel box (2) Steel base, (3) Steel loading frame, (4) Axial loading system, (5) Geokon data logger, (6) Weight indicator and gearbox motor controller board, (7) Load cell sensor, (8) Gearbox motor

Watermark monitor data logger model 900M was used to measure soil suction. The reading history provides a vivid picture of the soil suction profile; The watermark monitor data logger comes with one temperature sensor (200TS) (with 4.5 m wire lead, measures soil temperature) and seven watermark soil suction sensors model (200SS-15) manufactured by IRROMETER Company. For the installation of the watermark sensors, a special insertion tool is used; CAT No. 1017. The watermark insertion tool has an internal ejection rod inside the tube to push the sensor off tool once fully insertion into the borehole. The watermark monitor data logger model 900M uses WaterGraph 3.2 software (WG3). Automatically take a reading from one a minute to one a day. The stored readings are transferred to a computer for display.

2.1. Model Test Preparation

Models in loose, medium and dense soils were prepared using an electrical steel tamping hammer manufactured for this purpose as shown in Plate (2). The soils were prepared at three values of dry unit weight (16.3, 14.8 and 13.5 kN/m^3), for each one of the three gypseous soil samples. The bottom layer was overlain by a filter material used to allow free flow of water without soil erosion. This filter is compacted at a density equal to that of the soil sample. Two layers of geo-mesh were placed between the filter martial and soil layer to prevent the mixing of the soil with filter material. The weight required achieving the unit weight and the volume of the container layers was predetermined. The soil was divided into equal weights; each weight represents the quantity of soil required for each layer. The soil of each layer was compacted to a predetermined depth with the aid of modified jackhammer as presented in Plate 3; each layer was scratched by a spatula in order to provide good contact between the compacted layers. After that, the coring of the holes for IRROMETER Watermark Sensors was prepared by using a jackhammer drilling machine attached to high-quality Tungsten carbide cross head drill bits with dimensions (25 mm diameter and 500 mm length), then the final step was made with the use of the injection IRROMETER tool CAT No. 1017. The installation of the sensors was carried out within three different holes at depths of 100, 200 and 300 mm at the sides of the container. After completing the model-set up, the soil-saturation process was followed. The saturation process involved the complete saturation until the suction sensors readings approach to zero. The saturation process was performed by permitting the water to pass through the soil in upward-direction (from bottom to top of the model) with a steady flow and head of 2 m. Figure (4) shows the schematic diagram of the installed sensors and the saturating system which has been used in the model test.

Plate 2: Compacting soil model by modified jackhammer

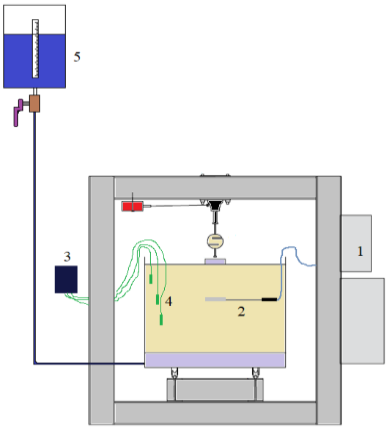

Fig. 4: Schematic diagram of the installed sensors and saturating system. (1) Geokon data logger, (2) Pressure cell sensor, (3) Irrometer watermark data logger, (4) Irrometer watermark sensors, (5) Saturating system.

3. Results and Discussion

By inserting three Irrometer sensors to depths of (100 mm), (200 mm) and (300 mm), and recording the suction readings with time, the figures below are obtained. Figures 5 to 13 present the variation of soil suction with time for 9 soil model tests (A1, A2, A3, B1, B2, B3, C1, C2, and C3), respectively. Overall, the figures indicate that the soil suction decreased with time when the soil is subjected to wetting from bottom to top, but the soil suction decreased with fast dropping.

For all soil models, the time needed to reach the zero suction (saturation state) increased with the increase of the initial dry density due to the decrease in permeability and void ratio. The initial value of suction for all soils increased with decreasing of the initial water content. The results revealed that there is a linear relationship between soil suction and its water content for the studied soil. Both total and matric suction values increased as soil water content decreased.

The drop in the readings of suction may be due to the effect of gypsum content on the adsorption of water that leads to the saturation of the sensors surrounding area.

The total suction is not affected by the increasing of compaction effort for the same water content. This behavior can be attributed to an increase in water activity occurred simultaneously with an increase in gypsum percentage, according to the chemical composition of gypsum ($CaSO4.2H2O$), the increase in gypsum percentage causes an increase in water molecules per unit mass of soil specimen. Because of uniformly distributed gypsum in the gypsum-sand mixture and due to it is composed of very fine particles with the large specific surface area, the slight increase in relative humidity leads to decrease in the measured total suction. The results showed that there is a sharp decrease in the measured total suction corresponded to the increase of the degree of saturation for the soil-sand mixture. Once the sand became unsaturated, the rate of increase in strength decreased, and in fact, the strength decreased when the suction was increased beyond some limiting value.

4. Conclusion

The soil suction decreased with time when the soil is subjected to wetting from bottom to top; the soil suction decreased with fast dropping.

For all soil models, the time needed to reach the zero suction (saturation state) increased with the increase of the initial dry density.

The initial value of suction for all soils increased with decreasing of the initial water content.

The drop in the readings of suction may be due to the effect of gypsum content on the adsorption of water that leads to the saturation of the sensors surrounding area.

The slight increase in relative humidity leads to a decrease in the measured total suction. The results showed that there is a sharp decrease in the measured total suction corresponded to the increase of the degree of saturation for the soil.

For unsaturated sand, the rate of increase in strength decreased, and in fact, the strength decreased when the suction was increased beyond some limiting value.

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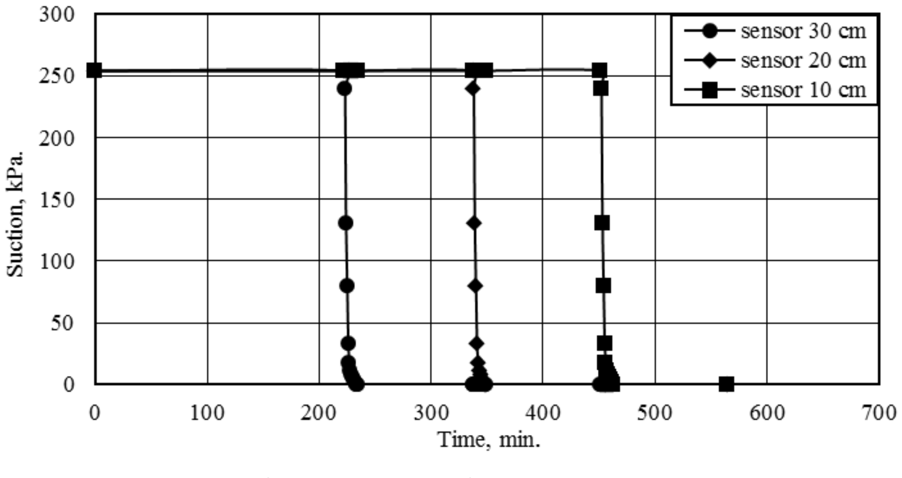

Fig. 5: Variation of soil suction with time for soil model A1 under initial loading.

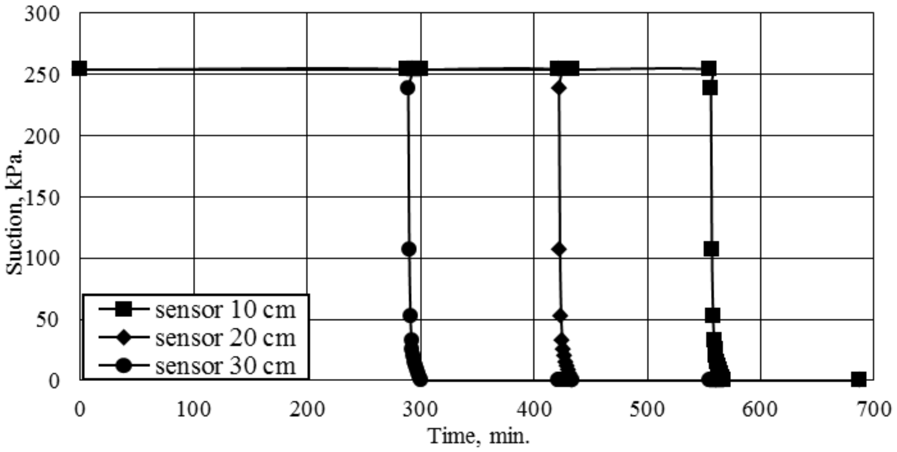

Fig. 6: Variation of soil suction with time for soil model B1 under initial loading.

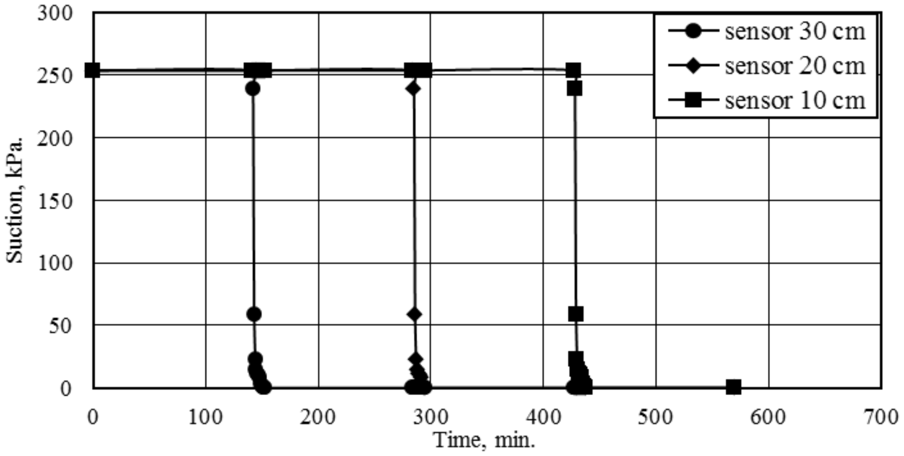

Fig. 7: Variation of soil suction with time for soil model C1 under initial loading.

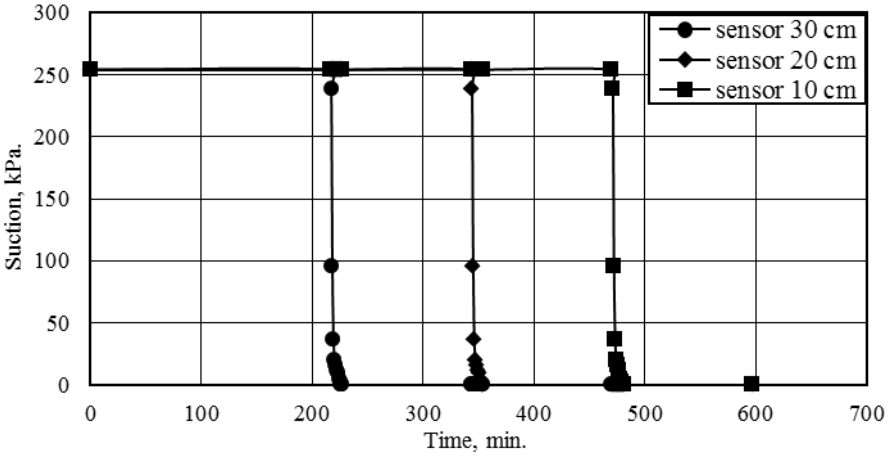

Fig. 8: Variation of soil suction with time for soil model A2 under initial loading.

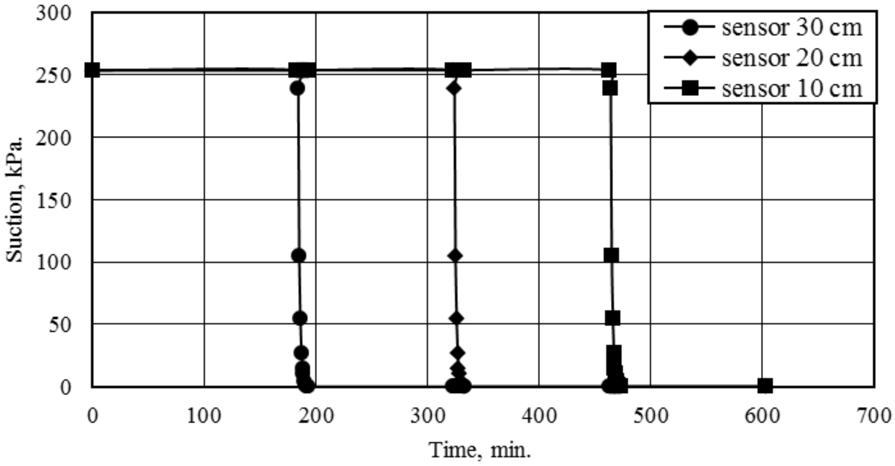

Fig. 9: Variation of soil suction with time for soil model B2 under initial loading.

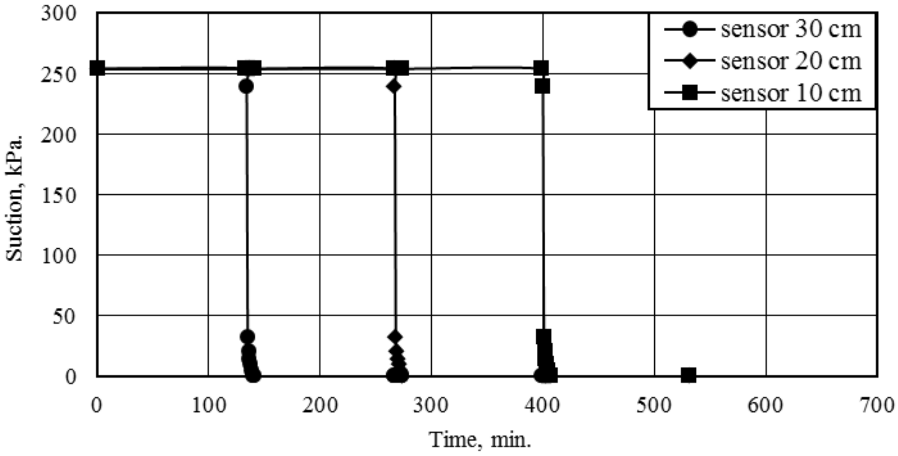

Fig. 10: Variation of soil suction with time for soil model C2 under initial loading.

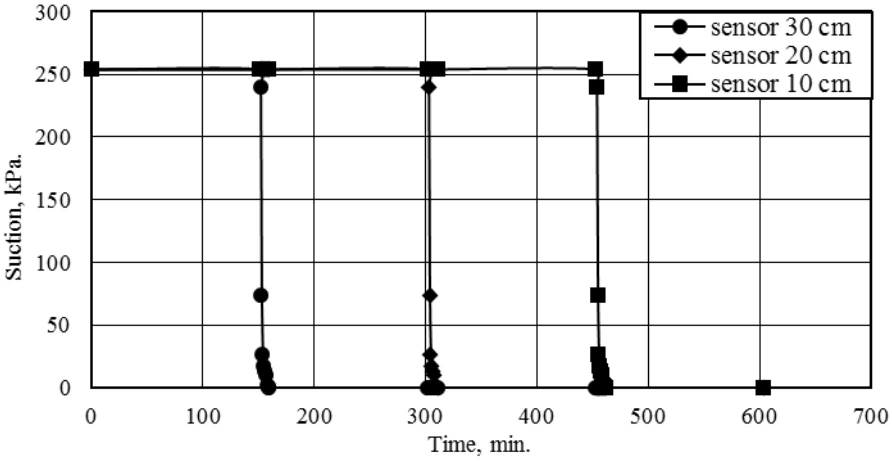

Fig. 11: Variation of soil suction with time for soil model A3 under initial loading.

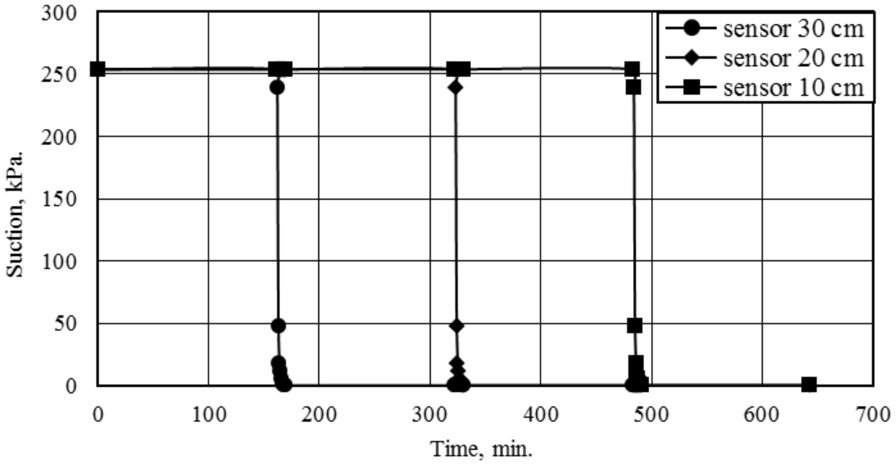

Fig. 12: Variation of soil suction with time for soil model B3under initial loading.

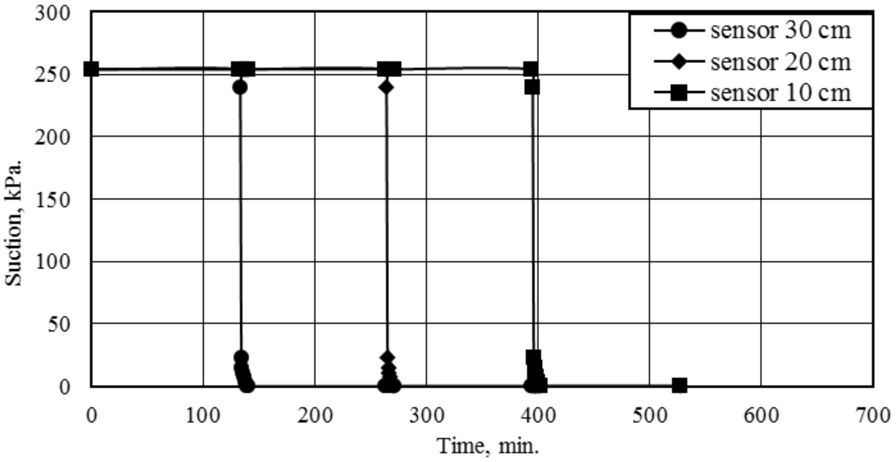

Fig. 13: Variation of soil suction with time for soil model C3 under initial loading.