

# Compaction of water-saturated soil by surface vacuuming

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**Abstract.** The results of laboratory studies of compaction of weak water-saturated soils using surface vacuuming are presented. Experiments on the compaction of water-saturated peat by the method of surface vacuuming under the screens were carried out on a special installation. The vacuum was created under round sealed screens of different sizes and stiffness. As the results of the experiments showed, the mechanism of compaction of weak water-saturated soils during vacuuming from the surface under the protection of a sealed coating is determined by the action of volumetric filtration forces. When vacuuming, in contrast to the compaction load, there is no soil venting around the perimeter of the compacted surface area, which significantly increases the efficiency of this method. And the use of flexible screens (geomembrane) opens up opportunities for construction. A series of compression tests was carried out to identify the similarities and differences in the consolidation processes when compacting different materials by vacuuming and equivalent load created by the press.

## 1 Introduction

The technology of surface vacuuming during compaction of weak water-saturated soils before the construction of facilities on them has been actively studied recently [1,2,3] and requires strict experimental justification for its successful application. This method is applicable in cases where a structure has to be built on top of weak soils. A classic example is the lathered areas or embankments of roads and railways built on weak clay soils.

Starting to study the complex processes of interaction of three-phase soil with changing air pressure on its surface, it is advisable to study the behavior of such a system in idealized (laboratory) conditions free from the influence of secondary factors and random effects.

Experiments on the compaction of water-saturated peat by the method of surface vacuuming under the screen of limited size were carried out at a facility that included a tank of cylindrical plexiglas connected to a vessel for feeding the soil with water, a measuring tank for collecting pumped water and a vacuum installation. The vacuum was created under round sealed screens of different sizes and stiffness. The pressure in the system was controlled by a vacuum gauge, the pore pressure under the screen was measured by

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capillary sensors screwed into the stamp. The sediment screen was measured by spicemaster mounted on cross-piece rigidly connected to the stand tank.

## 2 Research

Before the experiment, peat was mixed until a homogeneous mass was obtained, and then it was moistened with a feed from below with degassed water until water appeared above the ground surface. After one day, the ground surface was closed with filter paper, on which was laid a layer of coarse sand with a thickness of 0.5 cm. On the drainage layer was installed the screen so that its center coincides with the axis of the tank, and the edge was retreating from the walls of the tray around the entire circumference at an equal distance. On the screen connected to the vacuum unit capillary sensors stopped to monitor the pore pressure under the center and at a distance of 3 and 7 cm from the center. Pore pressure was recorded after stabilization of the sediments at the depths of 1 and 4 cm. Sediment surface was measured using 10, 30, 60 min from the start of the experiment and then every 30 min. The same time intervals were used in recording the amount of water in the measuring tank.

In the experiments, 2 types of screens were used: rigid Plexiglas, 10 and 20 cm in diameter, equipped with a vertical edge along the perimeter with a width of 5 cm and flexible polyethylene film, 20 and 24 cm in diameter, the edges of which were buried in the ground and closed from above with a layer of peat (Table 1). During the experiments, the open surface to prevent drying was constantly wetted with water and closed with a liquid peat mass.

**Table 1.** Parameters of the experiments on the degassing of the peat beneath the screen of limited size

№	Duration, hour	Sediment surface, cm	Maximum density, g / cm <sup>3</sup>		Screen type, diameter, cm
			to	after	
1	0.5	-	0.16	0.20	hard, D=10
2	1.5	2.00	0.16	0.23	hard, D=20
3	4.5	3.50	0.15	0.24	hard, D=20
4	2.7	0.50	0.17	0.23	hard, D=20
5	4.75	2.50	0.17	0.26	flexible, D=20
6	4.0	2.50	0.17	0.26	flexible, D=24

Peat compaction was accompanied by the creation of an intensive filtration flow, the speed of which changed as the soil compacted and stabilized simultaneously with the completion of the surface precipitation. Water supply from three sides from below ensured uniform distribution of the filtration flow in the soil.

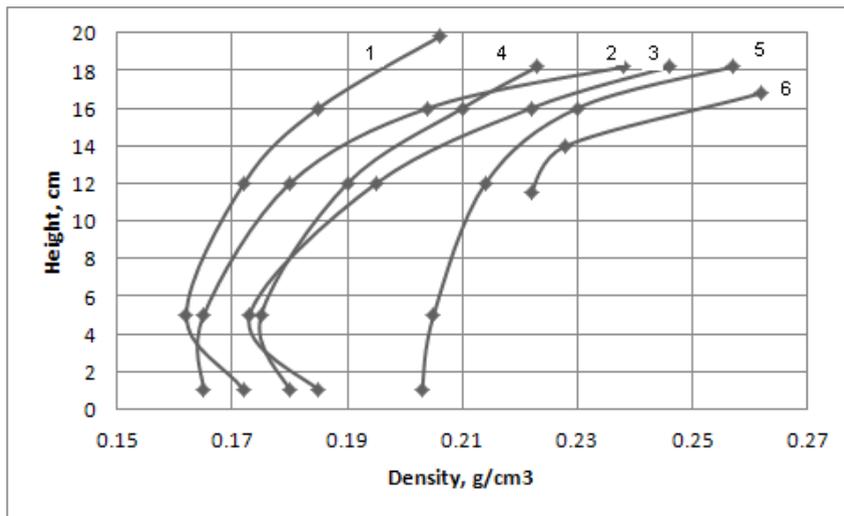
As shown by the experiments, the area of active compression in all experiments coincided with the area of reduced pore pressure. Presented in Figure 1 density distribution curves for the depth of the soil under the center of the coating after the experiment show that the surface in the layer thickness of 2-3 cm soil density depends on the depth of the vacuum and the duration of the experiment.

The depth of the sealing area depends on the coverage area. For example, in the experiments 2, 3, 5, 6, the density of soil at the surface after the experiment was 0,23-0,26 g/cm<sup>3</sup> (Table 1), and at a depth of 6 cm ranges from 0.17 to 0.23 g/cm<sup>3</sup>.

Thus, the mechanism of compaction of weak water-saturated soils during vacuuming from the surface under the protection of a sealed coating is determined by the action of volumetric filtration forces. At the same time, in contrast to the compaction load, there is no

soil flogging around the perimeter of the compacted surface area, which significantly increases the efficiency of this method. And the use of flexible screens (geo-membrane) opens up opportunities for construction.

A series of compression tests on odometers made of plexiglas was carried out to identify the similarities and differences in the consolidation processes when compacting real materials by vacuuming and equivalent load created by the press. The volume had diameter 37 cm, height 5 cm. At the bottom of the instrument and the stamp had a hole for connection with vacuum system.



**Fig. 1.** The change in the density of peat at the height of the soil layer. 1,2,3,4,5,6-number of experiments.

The design of odometers allows to test samples according to different schemes. Control samples were compacted under pressure according to the scheme "A". Vacuum sealing was carried out at full isolation of the sample from the environment according to the scheme "B1" and when the sample was supplied with water under atmospheric pressure according to the scheme "B2". In order to reduce the effect of trapped air experiments were carried out with the most water-saturated or air-dry samples.

Water-saturated samples were generally tested under conditions that prevent the sample from drying out. To this end, the installation scheme between the odometer and the vacuum pump included a flask filled with water, from the surface of which the inevitable evaporation occurred at low pressure.

Preparation of samples from 3 different materials (loam, peat and foam) was carried out based on the individual properties of each material. Samples from the loam were formed directly in the chamber of the device. 200g. soil in air-dry condition was poured into the chamber of the device and moistened with degassed water from below. After a day, the device was put under pressure and compacted with a load of 0.05 MPa to stabilize the precipitation. Then the device with the finished sample was weighed, measured the height of the sample and recorded its initial characteristics given in the Table 2.

**Table 2.** The parameters of the experiments on the evacuation of various materials under compression tests

Material	Scheme	Density,	Humidity	Porosity
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	tests	g /cm <sup>3</sup>					
		to	after	to	after	to	after
Foam	A,B <sub>1</sub> ,B <sub>2</sub>	0.95	0.92	12.5	8.2	13.6	9.6
Loam	A,B <sub>1</sub>	1.82	1.93	0.36	0.28	1.05	0.82
Peat	A,B <sub>1</sub>	0.96	0.97	7.69	5.94	13.73	10.57

The peat was saturated with water in the chamber of the device and then compacted with a load of 0.025 MPa.

Dry foam samples were compressed in an odometer with a load of 0.05 MPa. Then the load was removed, and the samples, restoring their shape, absorbed water from the bulb through the hole in the bottom of the device.

The essence of the tests was the simultaneous compaction of identical samples according to 2 different schemes of equal load. Identical samples were compacted by vacuuming under conditions not allowing the sample to be fed with water or dried, according to the scheme "B1". The same samples were tested according to the scheme "B2", in this case, pumping of water and air was carried out from under the stamp, and through the stamp filtered water from the vessel. Deformations in both cases were measured on a scale applied to the inner wall of the vessel. The pore pressure was reduced to 0.08 MPa, respectively, the atmospheric pressure sealing load on the seal stamp under the scheme "B1" and the value of the sealing filtration pressure during the test under the scheme "B2" were equal to 0.02 MPa. The control sample was tested according to the scheme "A".

We consider comparative experiments on compaction of samples of water-saturated foam rubber (ideal material) during vacuuming according to different schemes. Vacuum isolated sample scheme B1 was accompanied by a gradual decrease in pressure on the height of the sample: at the bottom the pressure is the same as the vacuum system, at the opposite end of the pressure reached this value after 4-5 minutes. Unbalanced atmospheric pressure acting on the movable stamp compacts the sample, causing it to exert compressive stresses; the atmospheric pressure is balanced by the reactions of the fixed base-bottom of the device. The filtration is damped, as the water extraction stops after the deformations are stabilized.

When tested under the scheme B2 pumping water from the sample was made from under the stamp, at the same time through the hole in the bottom of the device under the influence of atmospheric pressure in the chamber received water from the vessel. When the sample was fed with water, the pressure value under the stamp was equal to the pressure in the vacuum system, and the bottom remained equal to atmospheric pressure. The pressure difference ensured the existence of a constant filtration flow in the sample after stabilization of the sediment. In this vacuuming scheme, the effect of atmospheric pressure on the stamp was balanced by the filtration pressure causing the filtration stresses in the sample. During the experiment, the stamp of the device remained stationary, and the seal occurred from below, accompanied by filling the chamber of the device with water and separation of the lower end of the sample from the bottom, which coincides with the forecast of the behavior of the material with open porosity in the same conditions. The absence of stamp movements in the compaction process is explained by the fact that the filtration forces are much greater than the gravity forces from the weight of the stamp and the sample and do not cause resistance to friction forces. The completion of the consolidation of the samples, compacted by the filtration forces from below or by the unbalanced pressure from above, occurs simultaneously and the value of the stabilized precipitation is the same.

Dry samples of foam rubber were tested according to schemes A and B1. When vacuuming, the height pressure dropped instantly and became equal to the vacuum. The test on different schemes gave the same results.

Comparative tests of identical samples of water-saturated peat of the disturbed structure according to the schemes "A" and "B1" also gave the same results the constant height of the specimen the value of the pore pressure in the vacuum were established through 9-10 hours.

During the test of water-saturated loam samples, some delay in the relative vertical deformations was observed at the beginning of the experiment during vacuuming compared with the results of compaction by an equivalent load under pressure. The pressure at the opposite ends of the sample after stabilization of the sediment differs by 0.002 MPa. These differences have little effect on the amount of final precipitation and on the time of completion of the consolidation process. The completion of the consolidation process and the characteristics of identical samples tested under schemes an and B1 under conditions that do not allow the sample to dry are the same.

### **3 Conclusions**

The comparison of identical results after compaction is equal to the load for various schemes (Table 2) showed that the efficiency of compaction in a one-dimensional problem is virtually independent of the method and nature of the forces. The rate of pore pressure stabilization in height depends on the filtration coefficient of the material. So in the sample of dry foam stabilization of pore pressure is instantaneous, in the water-saturated foam for 4-5 minutes, in the sample of water-saturated loam - for 12-13 hours. The simultaneous completion of the consolidation process during vacuuming and compaction under pressure of identical samples gives grounds to consider the velocity of dispersion of excess pore pressure in both cases the same.

When the pore pressure decreases, at the beginning of the experiment, the air trapped in the small pores, expanding, transfers pressure both on the water and on the soil skeleton, which is confirmed by the delay of deformation during loam vacuuming compared to the results of conventional compaction. In this case, the behavior of the soil corresponds to the prediction of the behavior of the material with mixed porosity. However, with prolonged vacuuming, as the displacement of water, the pressure of the trapped air on the skeleton of the soil decreases and in General the process of compaction corresponds to the forecast behavior of the material with open porosity. Comparison of the results of experiments and preliminary forecast allows us to conclude that the interaction of the trapped air and the soil skeleton during the duration of evacuation is of a secondary nature.

### **References**

1. Z. G. Ter-Martirosyan, T.D. Olodo, *Geotechnical engineering*, **2** (2011)
2. A.Z. Ter-Martirosyan, Z.G. Ter-Martirosyan, *Engineering Geology*, **1** (2015)
3. L.I. Cherkasova, *Promyshlennoe i grazhdanskoe stroitelstvo [Industrial and Civil Engineering]*, **5**, 55-60 (2018)