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Measurement of stresses in soils of road embankments with the help of Mesdoses

Seidulla Abdullayev[1*], Aliya Izbairova[2], Kisselyova, Olga[3], Toktamyssov Aidos[4], Ivan Bondar[5]

[1,2,3,4]*Satbayev University, Almaty, Kazakhstan.*
[5]*ALT Mukhamedzhan Tynyshpaev University, Almaty, Kazakhstan.*

Corresponding author: Seidulla Abdullayev (*Email: s.abdullayev@satbayev.university*)

Abstract

The article is a review article devoted to the devices and methods of their use for the experimental study of the stress-strain state of the earth bed of road and railway embankments, approach embankments to bridges, and transport interchanges. Today, an important task in the construction of embankments is the determination of the expected settlement. To measure the stresses in the soil mass of the roadbed, sensors based on strain gauges (Messdozes) are used. The authors consider several types of messdozes according to the ‘classical scheme’, analyze the revealed disadvantages of different designs during laboratory and field tests, and describe the ways of their elimination. The advantages of the modernized scheme of messdozes are described, and the calibration of the modernized sensors (Messdozes) is considered. Modernized sensors have been tested by students of the scientific circle ‘Transport constructions’ under the direction of Associate Professor Bondar I.S. during a series of laboratory experiments carried out on the basis of the testing laboratory ‘Testing of track and artificial constructions’ of ALT University named after Mukhamedjan Tynyshpaev, Almaty.

Keywords: Massdose, Strain gauge, Stress in the ground.

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1. Introduction

One of the most important tasks of designing embankments of the earth bed of motorways is to determine the value of the expected soil settlement under the influence of transport load. However, a comparison of calculated and observed settlements shows that this task is not always successful, especially when erecting on weak soils. The development of inadmissible settlements, sometimes exceeding the calculated ones several times, leads to an increase in the uneven deformation of the roadbed and its emergency condition.

The reasons for low accuracy of settlement calculations are, on the one hand, imperfect engineering methods of calculation and, on the other hand, deficiencies in the methodology of determining deformation characteristics during engineering and geological surveys.

Settlement calculation methods and methods for determining the mechanical properties of soils are constantly being improved. The main tasks in the creation of new and improvement of existing calculation methods are the determination of stresses developed under transport load in the soil mass, the size of the deformation zone and the study of deformations along their extent in the body of the earth bed of motorways.

Theoretical foundations of methods for measuring stresses and deformations in soils, especially their metrological part, are the least studied so far, and therefore require special attention of researchers.

The true picture of the stress state of the soil, which is a multiphase system consisting of mineral particles, the pores between which are filled with water and gases, is extremely complex. The stress state can be considered as a complex of interacting contact stresses at the points of contact of mineral particles, stresses in the body of the particles themselves, pressure in the liquid and gases filling the soil pores.

In soils, the sensitivity of the primary instruments and the accuracy of the measured values are problems in determining the stress state of the subgrade.

There are also computational methods for determining the stresses in the soil, but these methods cannot fully account for the heterogeneity of the soil mass. Dispersed soils may contain various mineral and organic components, water, ice of different temperatures and various gases. Obviously, the more heterogeneous the composition of the soil mass, the more difficult it is to reliably determine the arising stresses in different parts of the foundation [1-3]. Therefore, direct determination of stress in the soil is the most rational solution. The device for measuring stresses in the soil is called - mesdose [4].

In the process of mutual displacement of particles during soil compaction, the points of their contact change, and consequently, the stresses in the particles themselves and at the contacts. The difference of configurations, sizes and deformative properties of particles creates a huge variety and uniqueness of stress states, which can be described only by statistical methods.

In this connection, when solving engineering problems, the assumption is made that the normal or tangential stresses at any site are equal to the mean integral value of the projection of true stresses, respectively, on the normal or tangent to this site.

The mean integral values of stresses correlate with strength and deformation properties of soils with a sufficient degree of accuracy and reliability, and therefore fulfil the requirements of engineering problems.

However, for scientific purposes, these stresses can be used only when considering phenomenological models of soil. When creating physical models, it is necessary to know the true stress state of the soil. It should be noted that the true stresses at the contact points of soil particles can exceed the average integral stress over the site by two orders of magnitude.

Taking into account the assumption of the mean integral stress, the stress state in the investigated point of the soil massif can be determined by the stress tensor, i.e., in the case when six independent components are known (e.g., the value of normal stresses at six differently oriented sites).

Therefore, the task of experimental study of the stressed state of the soil is reduced to the determination of normal stresses at differently orientated sites. For this purpose, normal stress sensors - messdozes - are used, which are placed in the soil and contact with soil particles, pore water and gas with their sensitive elements [5, 6].

The simplest messdozes usually have the form of a cylindrical disc, one or two planes of which are sensing elements - membranes sealed along the contour (Figure 1, scheme Figure 2) [7].

Figure 1.
General view of a messdose.

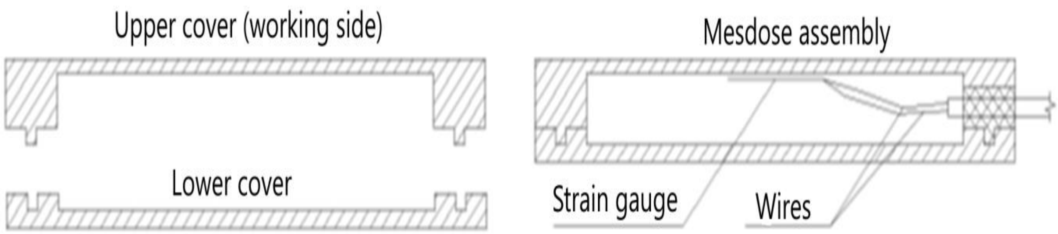

Figure 2.
Scheme of membrane (Shell) mesdose.

The principle of operation of the mesdose: install the device in the soil area of interest; collect the load from some area of the soil and apply it to the element with known deformation characteristics; connect strain gauges and after interpreting the obtained data on the deformation of the element, obtain the final pressure transmitted to the mesdose, it will be equal to the internal stresses of the soil [8].

In order to measure the ground stress most accurately, it is important that the strain element being recorded is as sensitive as possible to the applied loads. Membrane mesdoses are widely used, with the role of the capturing element being fulfilled by the sheath and the strain gauges being connected to it. However, over time, a solution has been devised to increase the sensitivity of such a mesdose. It is proposed to install a thin metal plate under the membrane. The essence of this improvement lies in the fact that the membrane collects pressures over its entire surface and transmits it to the bar below, which already works entirely on bending. A strain gauge is connected to the beam, which picks up the external pressure. Other things being equal and proper calibration, the beam mesdose can be significantly more sensitive and, as a consequence, more accurately capture the internal stresses of the soil mass [7, 8].

According to N.M. Gersevanov, there are 3 phases of soil stress-strain state: the phase of normal compaction, the phase of shear, and the phase of soil bulging.

The main difference between these phases is the volume of soil that has lost its bearing capacity and is working in the zone of plastic deformations.

The loss of bearing capacity of soils occurs by tangential stresses [1]. Mesdoses measure normal stresses, which, according to the Mohr-Coulomb law, are directly proportional to tangential stresses [2, 3]. Qualitatively assembled and competently installed mesdoses can most accurately determine the stress-strain state of a soil foundation [9].

A mesdose measures the average integral value of the normal stress in the soil over the area of the membrane that deflects under the measured stress (Figure 3).

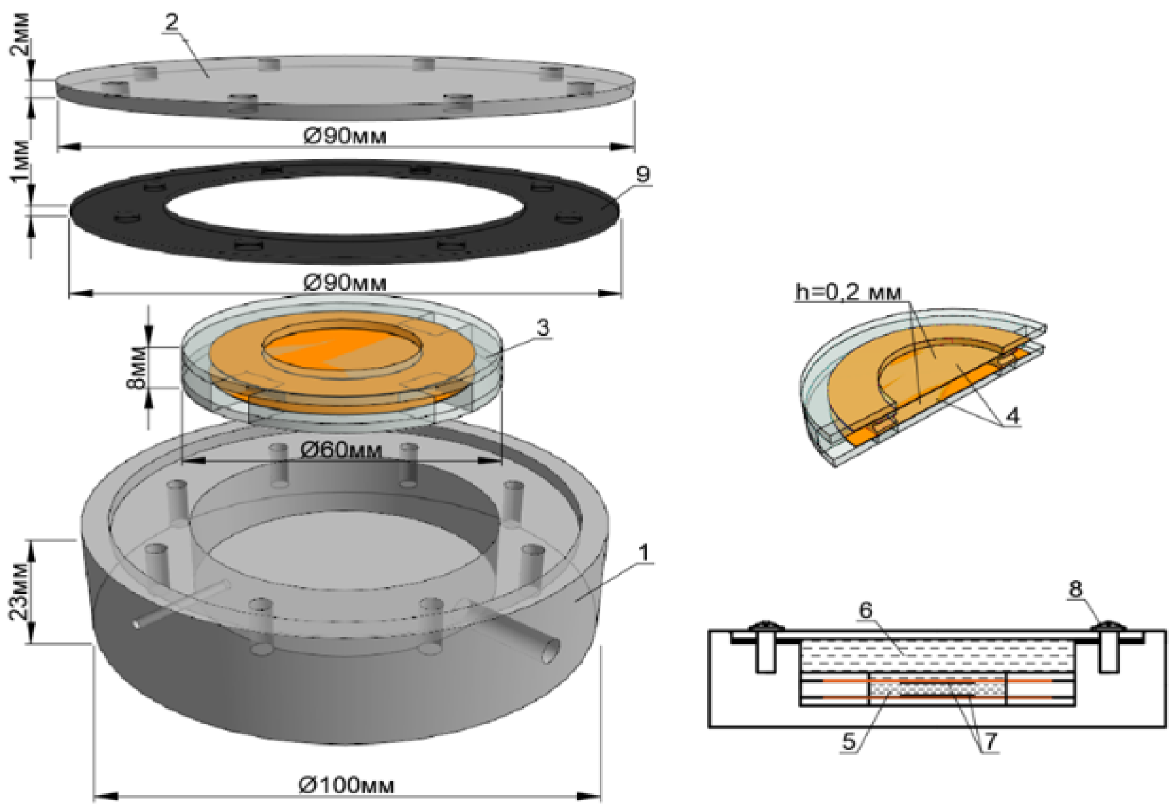

Figure 3.
Schematic diagram of the messdose device.
Note:1 - body; 2 - working cover; 3 electrochemical cell; 4 - elastic metal membranes; 5 - electrolyte; 6 - hydraulic fluid; 7 - electro-insulating coating; 8 - screw; 9 - rubber gasket.

Deformations of the inner surface of the membrane (elongation in the centre and shortening on the support) are converted by strain gauges glued on the membrane into an electrical signal, which is transmitted to the secondary device of the measuring system via a communication channel. The signal of the secondary instrument is decoded as normal stress acting on the massdose using a tare graph [10].

The soil stress sensor consists of a cylindrical steel housing with a rigid bottom protecting the internal structural elements from moisture and soil particles, an electrochemical cell and a working cover which is a steel plate [6].

Inside the electrochemical cell made of electro-insulating material (acrylic) two round elastic metal membranes, which act as electrodes, are rigidly pinched along the contour, to which contacts are soldered, which are led outside the sensor body. The membranes are arranged parallel to each other, and their inner surfaces are covered with round elastic electrically insulating coatings made of rubber. The presence of the protective coating in this design is dictated by the characteristic of the bending moment arising in the membranes when they are deformed under load.

An electrolyte solution is poured between the elastic metal membranes. Between the upper elastic metal membrane of the electrochemical cell and the working cover of the sensor there is a hydraulic deaerated liquid, which transmits mechanical deformations from the medium under study. The tightness of the connection between the working cover and the cylindrical body of the sensor, made with the help of eight screws, is provided by an elastic rubber ring gasket.

The design of the sensor takes into account the previously obtained results on the study of the operation of mesdoses, which showed the relationship between the measurement results, mechanical parameters of mesdoses and deformability of the soil. At the same deformability of mesdose and soil the measurement error is minimal. The value of relative error for rigid mesdoses is directly proportional to the ratio of their height to diameter.

2. Methods and Research

At the Department of 'Architectural and Structural Engineering', ALT University named after Mukhamedjan Tynyshpaev, Almaty, the student scientific circle 'Transport Structures' was created. Under the guidance of I.S. Bondar, Candidate of Technical Sciences of VAK RF, Ph. D of MES RK, associate professor (associate professor) of MNiVO RK, the intellectual system of strain-force monitoring 'TENZO' (Figure 4) was developed, with the help of which the long-term research of various strain gauges for measuring VAT of transport structures is carried out [11-19].

The complex of ISDSM 'TENZO' includes the following devices: a system of remote transducers (mesdos, shear sensors), information-measuring system ISDSM 'TENZO' and a personal computer. The software and hardware of the TENZO IMSMS creates the possibility of performing experiments on models in real time [20].

Figure 4.
Intellectual system of deformation-force monitoring «TENZO».
Note:1 - protected laptop GETAC V110, with a high degree of protection of the case (IP65),
2 - measuring electronics with industrial bus «Module PME-55», 3 - cable connecting the voltage converter (messdose); 4 - cable connecting «Modules PME-55»; 5 - battery HAZE HZB-12-230; 6 - Sine inverter HANTER Prowatt SW 2000i.

Stresses in the soil mass of the earth bed of road and railway, approach embankments to bridges and traffic interchanges were measured by strain gauges - mesdoses of Y.N. Murzenko design (MK-26, MK-37, MK-54) and mesdoses of G.E. Lazebnik design (M-96). The sensors used in the experimental studies are shown in Figure 5.

Figure 5.
Stress and strain transducers.
Note:1 - messdose MK-24, 2 and 3 - messdose MK-37, 4 - messdose MK-54, 5 - messdose of G.E. Lazebnik design.

2.1. Experimental Part

Initially, two rigid square metal boxes with dimensions of 400×400×400 mm filled with different soil were chosen as earth embankment models [21-23]. The area of the die base is equal to 0.1225 m2. Upgraded sensors (messdozas) located in the soil (earth embankment models) under the stamp: 1 - sensor at a depth of 20 mm; 2 - at a depth of 100 mm; 3 - at a depth of 200 mm; 4 - at a depth of 300 mm; 5 - at a depth of 380 mm.

During the experiment, pressure was applied to the soil sample through the cantilever-arm system in steps according to the method of laboratory determination and characteristics of strength and deformability according to GOST 12248-2010. Settlement of the die in the model was measured by deflection gauges of the TsNIISK and 6-PAO systems with a division value of 0.01 mm, an indicator of the hour type ICH-10 and an electronic digital displacement sensor (Figure 6) [20]. The experiments were continued until the bearing capacity of the soil embankment model was exhausted.

Figure 6.
Displacement sensors: clock type indicator ICH-10, deflection gauges of TsNIISK and 6-PAO brands and with a clamp, with an electronic-digital displacement sensor on top.

In the course of field tests on various objects of road construction (earth bed, approach embankments to bridges and interchanges [24, 25] and laboratory experiments more than 180 sensors made according to the ‘classical scheme’ were used, the main causes of poor quality of sensors and their failure were revealed: breakage of the strain gauge leg (contact), ingress of air and moisture in the place of cable entry into the sensor, breakage of the signal cable itself, short-circuit of the strain gauge to the messdose body, peeling of the strain gauge from the sensor body, defect in the manufacture of the messdose body.

To reduce the number of defects the following recommendations were proposed: introduction of a glass-textolite board into the messdose housing for rigid fixation of the wire inside (Figure 7 and Figure 8), two-stage sealing of the housing, use of cyanoacrylate glue ‘SuperMoment, universal second’ instead of glue BF-2, transition to a new type of signal cables KSPV (previously used UTP cable).

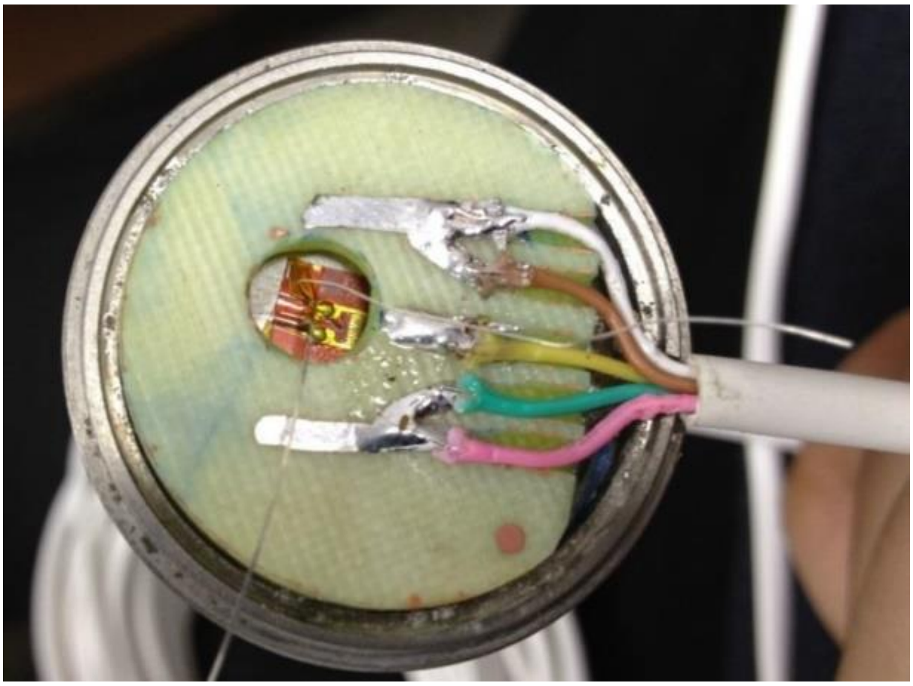

Figure 7.
General view of modernised messdose.

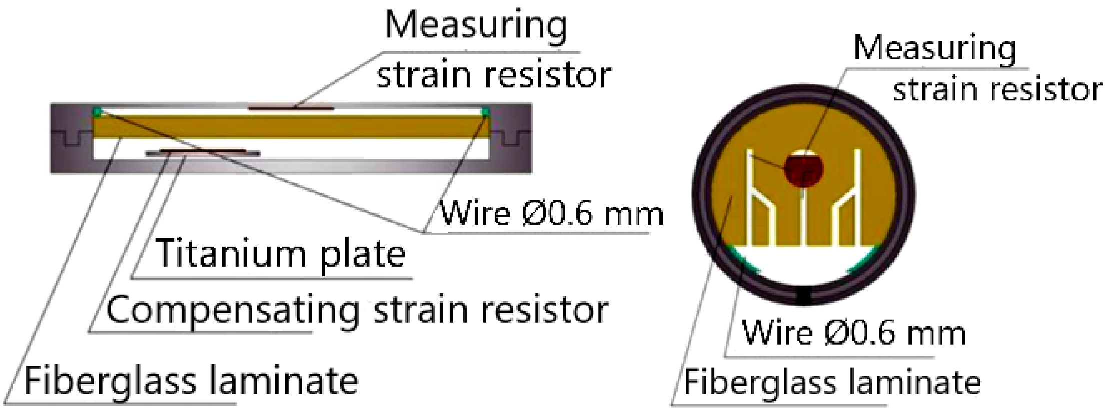

Figure 8.
Schematic diagram of the modernised messdose.

Sealing was performed using epoxy resin in two stages. In the first stage, the messdose body with the connected cable was clamped to the plastic mould for casting with a clamp. Then epoxy resin was poured almost up to the top of the sensor body. In the second stage the clamp was removed until the first layer was fully cured (for better adhesion) and the second layer of epoxy resin was poured, which completely hid the sensor. This scheme does not allow the possibility of air and moisture from the outside to get into the sensor housing. The messdose remains sealed and the cable remains rigidly attached.

Earlier for sticking the strain gauge on the working surface of the messdose the glue BF-2 was used, which required temperature treatment in the oven, that considerably complicated the process of sensor assembly and increased the probability of defects during manufacturing. To simplify the gluing of strain gauges it was undertaken to use cyanoacrylate glue (glue 'SuperMoment', universal second). The operation of the sensor was not affected by changes in the type of glue, and the probability of sensor detachment was reduced to zero [7, 8].

2.2. Calibration of Modernised Sensors (Messdoz)

Modernised sensors (messdose) of membrane type total pressure measurement were introduced into the soil sample (Figure 7). They were used to verify that the compression compression conditions were fulfilled and to monitor the loading of the specimen. The sensors were assembled on the basis of the testing laboratory 'Testing of track and artificial constructions', under the direction of Bondar I.S., have a round shape, the body is made of steel plates. On the working surface of the sensor is glued strain gauge (Figure 9) brand PFL-10-11 designed to measure deformation and use as sensitive elements of measuring transducers (Manufacturer: Tokyo Sokki Kenkyujo Co., Ltd. Supplier: Japan M)

Figure 9.
Strain gauges for testing metal elements.

As the total pressure increases, the working surface flexes, causing the contact length of the strain gauge to change and consequently its resistance. These data are recorded by the recording equipment of the complex ISDSM «TENZO». The massdose calibration was carried out in an aerostatic calibration tank (Figure 10) according to the method [26].

Figure 10.
Aerostatic calibration tank.

On the left - general view, on the right - messdose in the tank with sand.

3. Results

According to the results of the laboratory experiment, a graph of the dependence of the pressure in the ground on the pressure on the sample under the die was plotted (Figure 11).

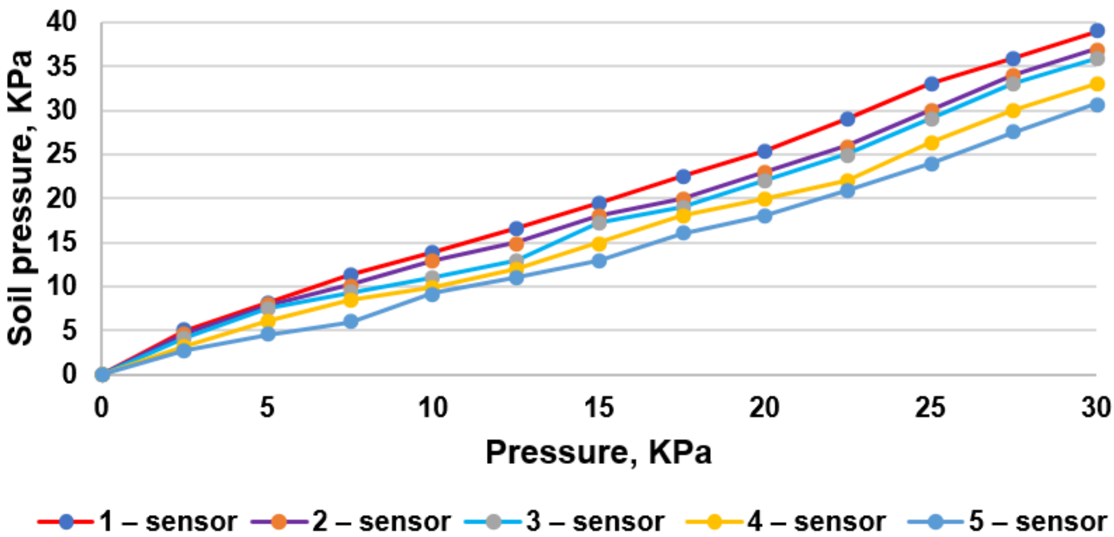

Figure 11.
Graph of dependence of pressure in the ground on the pressure on the sample under the die.
Note:1 - sensor at a depth of 20 mm; 2 - at a depth of 100 mm; 3 - at a depth of 200 mm; 4 - at a depth of 300 mm; 5 - at a depth of 380 mm.

Combined graphs of the dependence of the average die settlement on the load for each series of experiments are shown in Figure 12.

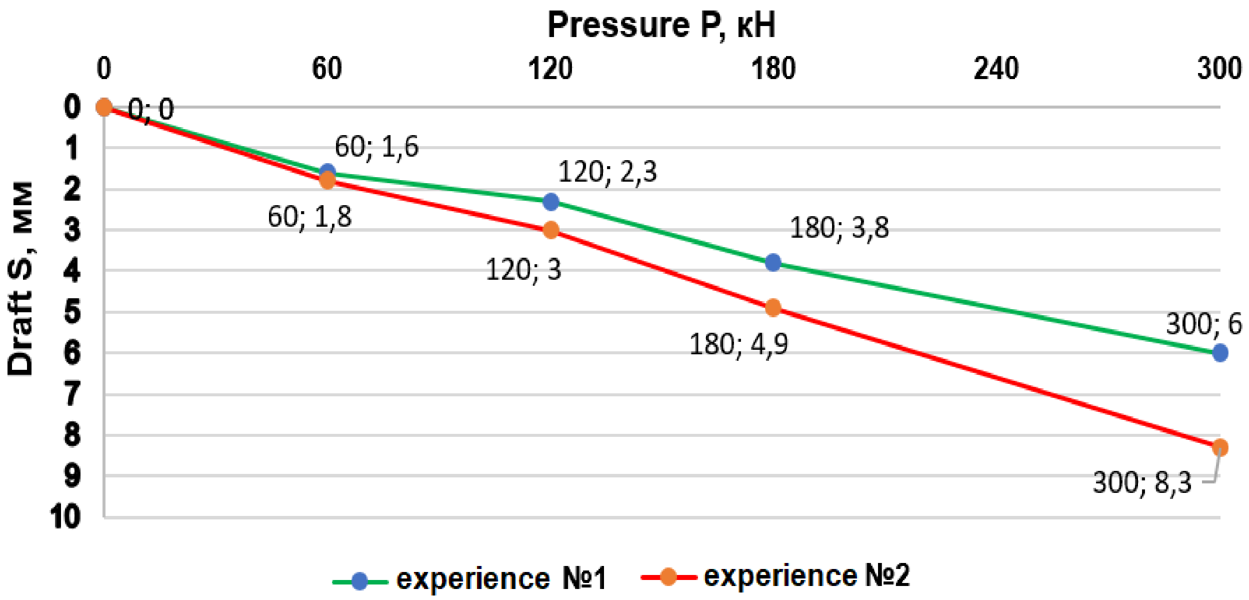

Figure 12.
Graphs of the dependence of the precipitation on the load.

4. Discussion of the Results

According to the results obtained by messdozas (Figure 11) placed in the model of the embankment of the earth bed from different soil we can make the following conclusions: 1 - the load reached 30 kPa, after this step there was a conditional stabilisation of the soil; 2 - the best conditions of work of messdozas is their placement in the layer of soil at the contact with the bottom of the stamp (depth of 20 mm); 3 - the settlement of the stamp (Figure 12) in the model for the series of experiments №1 - was 6 mm, and for the series of experiments №2 - was 8.3 mm.

The experiment lasted 14 days. During the experiment not one sensor from the total pressure did not fail and worked qualitatively. The measurement error did not exceed 9.8 %, which is a good indicator for modernised sensors.

5. Conclusions

The modernised scheme eliminates all the disadvantages of the 'classical' scheme of sensors, also revealed during many experiments of foreign scientists [22, 27, 28] with their use. In the modernised scheme, it becomes impossible to break the strain gauge leg, as it is soldered to a rigidly fixed board. There is no possibility of short-circuit of the strain gauge leg to the sensor body. The two-stage sealing eliminates the possibility of air and moisture getting into the sensor housing. The cable breakage is prevented by good soldering of the cable to the internal sensor board.

The modernised sensors were tested by the students of the scientific circle 'Transport Structures' under the guidance of Associate Professor Bondar I.S. during a series of laboratory experiments conducted on the basis of the testing laboratory 'Testing of Track and Artificial Structures' according to the method [29].

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