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The effect of a change in the load on the embankment crown on water level fluctuations inside the body

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Abstract

The aim of the study was to determine the influence of the load on the water accumulation embankment crown on changes in the course of the filtration curve in its body. The study was carried out with a medium-size filtration apparatus. We made a model of hydrotechnical embankment with the following dimensions. Width: base 2.0 m, crown 0.5 m. Slope inclination: waterside 1:1.5, landside 1:1. Embankment height 0.6 m, width 1.0 m, weight 900 kg. The construction material included a homogeneous mineral subsoil classified as silty medium sand (siMSa). The embankment model made in a medium-size apparatus kept the accumulation level at a height of 0.5 m. With data from the recording systems, we determined the course of the filtration curve. Next, we kept on loading and relieving the embankment crown using an actuator and a VSS plate with a diameter of 300 mm. During this process, we recorded changes in the level of the water table inside the embankment. A decrease in the water table was observed as a result of increased load. Once the load on the embankment crown was reduced, the water level inside the embankment increased. The embankment model built from natural soil works well as a structure that keeps damming water in a continuous manner. The use of drainage in the form of a stone prism at the foot of the landside slope allows protecting the slope against the negative influence of filtration (piping, liquefaction).

Key words: *embankment model, filtration, medium size filtration apparatus, modulus of elasticity, water level fluctuations*

INTRODUCTION

Soils, due to their geological structure, are characterized by variability in composition, including layering and discontinuities [HANDY, SPANGLER 2006]. As a discontinuous medium, the soil consists of a soil skeleton, i.e. grains and particles of various shapes and sizes, water, which can occur in three states (liquid, air, solid) and air filling the soil pores [STRZELECKI *et al*. 2008; VOGEL *et al*. 2001]. Due to its discontinuity, the soil medium behaves differently than materials of continuous construction under the influence of various loads. The assessment of the density of embankments is one of the basic tests during the implementation of each investment related to earthworks. The process of soil loading and deformation is an irreversible process, which is why it is so important to properly incorporate and compact the soil during the constriction of each earth structure [BRYANT *et al*. 2007; SPOOR 2006]. Currently constructed embankments, i.e. road embankments, in order to reduce and eliminate long-term settlement, as well as increase the load capacity and strength of the soil are properly compacted during construction [CHEN *et al*. 2007; HARA *et al*. 2007]. Making the appropriate compaction can be achieved by compacting or vibrating. Summary, assessment of soil compaction during earthworks should be carried out as soon as possible so that the process of construction works is carried out efficiently and without unnecessary suspension of construction.

The filtration factor is mentioned in the literature as one of the most important parameters determining the safety of these hydrotechnical constructions [BARAN *et al*. 2016; CHALFEN *et al*. 2008; CHOLEWA, BARAN 2013]. Too high water filtration through embankments during periods of high floods can cause deformations of slopes, as well as soil displacement or suffusion [OH, VANAPALLI 2010; THUO *et al*. 2015]. The value of the filtration coefficient decreases with increasing material density and the fraction content smaller than 0.2 mm. The amount of water filtration through the embankment also depends on the degree of compaction and the type of soil. The filtration speed should not cause soil to be washed inside the dam or the slopes to be damaged.

Testing of filtration through embankment models made on a semi-technical scale is sporadic due to their high labour intensity. The results of model tests of filtration through embankments are most similar to filtration through natural embankments. The models offer the possibility of incorporating additional elements, such as reinforcement, drainage and installing measuring devices.

The results of the model tests can be the basis for forecasting the behaviour performed on a 1: 1 scale. Embankments built as elements of surface watercourses work mainly in flood conditions for several days. Geometric dimensions of cross-sections of embankments, damming level and hydraulic fall values are generally much safer than those adopted in model tests. Therefore, the presented results have a large safety margin in relation to the expected values in real objects of similar construction.

Geosynthetics meet a number of functions that can be divided into two types: hydraulic and mechanical. Depending on the type of material used and the example of use in a given structure, it can fulfil several functions simultaneously [BEZUIJEN, VASTENBURG 2013; CHOLEWA, KUTIA 2019; HSIEH 2016; PALMEIRA 2009; PRITCHARD *et al*. 1999; TATSUOKA 2008].

The hydraulic functions of geosynthetics include:

- filtration – it is based on the controlled flow of liquid and gas molecules, while stopping particles of native soil [BATALINI DE MACEDO *et al*. 2017],
- drainage – collecting and transporting liquids in the plane of the product [MAHESHWARI, GUNJAGI 2008].

Properly designed drainage must have protection in the form of reverse filters (gravel-sand filter around the drainage pipe). This requires applying in the mixture of 2–3 types of backfill with different granulation. Therefore, it is advisable to use geotextiles as filtration layers, eliminating the need for costly mix selection and the number of filtration layers. The use of geosynthetics in dewatering operations using drainage make it easier to install wires in the ground, while simplifying and shortening the time of investment implementation.

CHARACTERISTICS OF THE GROUND MATERIAL AND GEOTEXTILE

Silty medium sand was used to build the embankment. Physical and mechanical geotechnical parameters of natural, mineral soil were determined in the laboratory of the Department of Water Engineering and Geotechnics of the University of Agriculture in Kraków. Grain-size parameters were also determined. The gravel fraction content was 15.74%, sand fraction 63.84%, silt fraction 17.58%, clay fraction 2.84%, rock fraction did not occur. According to the standard, we classified the soil as silty medium sand (siMSa). The density of solid particles of the material amounted 2.71 $g \cdot cm^{-3}$, optimal moisture content was 7.8%, the maximum bulk density of the rock framework was 2.115 $g \cdot cm^{-3}$.

A geosynthetic material was built into the embankment model. The Secutex 401-GRK 5C geotextile used to build the drainage is a type of white needle-punched geotextile fabric, made of polypropylene. This geotextile performs a separation and filtration function, protecting different soil layers from mixing. The product is also used in road and water construction, construction of tunnels and landfills.

The material used to build the drainage came from the Porphyry and Diabase Mine in Zalasie. The material was labelled porphyry broken stone with granulation of 31.5–60.0 mm. According to the manufacturer's description, the material meets the requirements of the PN-EN-13043:2004 standard and can be used for drainage works, foundations for roads with heavy and very heavy traffic, as well as the foundation for squares and yards [BRACHMAN, GUDINA 2008].

TEST SITE CHARACTERISTICS

The model tests were carried out in a prototype, medium-size apparatus for testing filtration through embankment models, which, for simplicity reasons, we will refer to as hydraulic channel. Internal dimensions of the apparatus are respectively: length 6.0 m, width 1.0 m, height 1.2 m. Photo 1 shows the general view of the channel and its structural elements.

The constructed experimental embankment was 0.6 m high. The inclination of the waterside slope was 1:1.5, while the inclination of the landside slope was 1:1. The length of the base was 2.0 m. Under the embankment base, there was a 0.04 m thick layer of clay playing a sealing function. Drainage of the slope base was performed from the landside. The ground was removed at a height of 0.15 m to make space for a stone V-block a right triangle cross-section. The space from where the ground was removed lined with the Secutex separation and filtration geotextile and covered with porphyry broken stone (Fig. 2). Drainage dimensions were determined based on previous studies. The embankment model did not have drainage elements and the filtration curve could be observed.

Piezometers were installed in the hydraulic channel in order to control the water level. They are located along the axis of the embankment in the following order: P1, P2, P3, P4, P5, and P6. The distance between the piezometers was 50 cm (Fig. 2).

A system of pipes and overflows made it possible to adjust the quantity of incoming water and measure the filtration output through the embankment. The measurement equipment of the apparatus enables continuous 24/7 testing. The measurement instrumentation includes (Photo 2):

- temperature sensors for top and bottom water,
- hydrostatic level transmitters,
- turbine flow meter mounted on the drainpipe of the overflow chamber,
- electronic digital recorder.

Photo 1. Medium-size apparatus for testing filtration through embankment models; a) front wall view, b) soil compaction in the model, c), d) damming water by the model (phot. *M. Cholewa*)

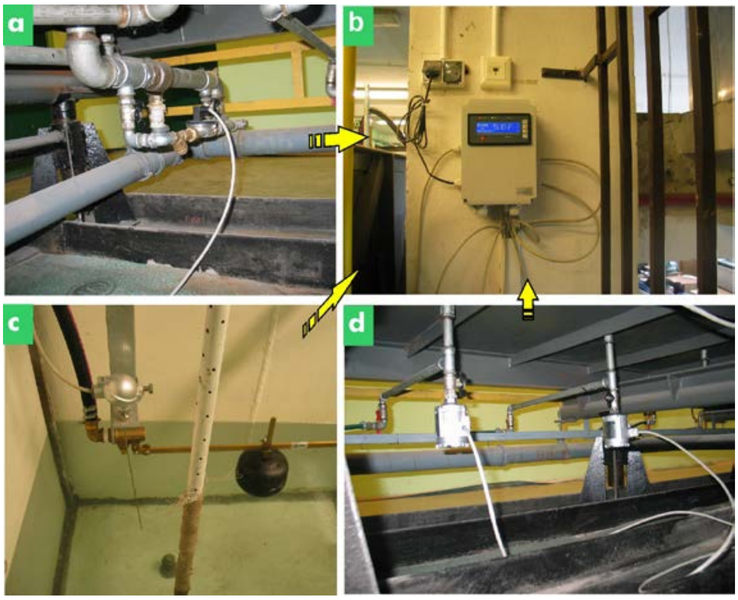

Photo 2. Measurement sensors transmitting data to the digital recorder: a) turbine flow meter mounted on the drainpipe of the overflow chamber, b) electronic digital recorder, c) temperature sensors for top water, d) hydrostatic level transmitters (phot. *M. Cholewa*)

Once the model was built, water damming took place until reaching the level of 50 cm. The assumed damming was obtained after 5 h, which means that the damming speed was 10 cm·h^{-1}. During channel filling, piezometers kept reading water levels every 6 min.

RESULTS

WATER TABLE LEVEL IN INDIVIDUAL PIEZOMETERS

The first reading was taken 24 min after starting the test. At this moment, water appeared in the P1 piezometer at a level of 4.2 cm (Fig. 1). In the P3 piezometer, we recorded the presence of water exactly 3 h after the damming started, the water level being 0.7 cm. After 4 h we recorded a reading of 6.7 cm for the P4 piezometer. After two days water appeared in the piezometer (P5) (Figs. 1, 2). Piezometer P6 didn't record measurements.

RESULTS AND ANALYSIS OF THE VSS PLATE EMBANKMENT LOADING

Determination of the original modulus of elasticity E_1

Embankment modulus of elasticity was determined by loading the VSS board in accordance with the guidelines of PN-S-02205:1998. During the test, we measured vertical deformations (settlement) under the influence of static

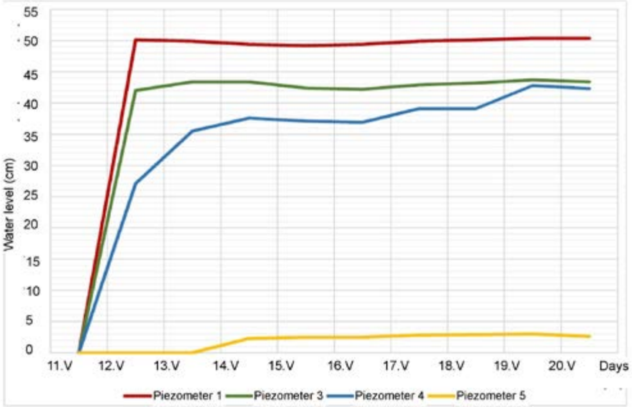

Fig. 1. Location of the water table in particular piezometers during damming and 10 days after its completion; source: own study

pressure exerted by a steel round plate. The diameter of the plate was 300 mm. A hydraulic jack was used to exert appropriate pressure on the plate.

After installing the VSS set, the test started with a pre-load of 0.02 MPa. Pre-readings were taken from dial gauges.

In the form, next to each reading the following data: reading time, manometer reading and sensor reading. At the final stage, the embankment was loaded to 0.25 MPa.

Once the required final unit load was reached, and with the difference between the two consecutive sensor readings being less than 0.05 mm, the load was relieved to 0.00 MPa in steps of 0.1 MPa. The sensor readings were repeated every 2 min.

Determination of the derivative modulus of elasticity E_2

Once the slab has been completed relieved, pre-pressure was applied again, this time with 0.05 MPa. Further, we proceeded in the same way as for the original modulus of elasticity E_1.

Calculation of the modulus and deformation index I_o

The plate load tests were used as a basis for calculating the modulus of elasticity (E) and the deformation index (I_o) for the two trials. The modulus of elasticity E (MPa) for both VSS trials was calculated with the use of the following Equation (1):

$$E = \frac{3\Delta p}{4\Delta s} D \tag{1}$$

Where: Δp = pressure difference in the range from 0.05 MPa to 0.15 MPa (MPa); Δs = settlement increase corresponding to the difference in pressure above (mm); D = diameter of the loaded plate (mm).

The effective strain I_o was also calculated for both trials using the Equation (2):

$$I_o = \frac{E_2}{E_1} \tag{2}$$

Where: E_2 = secondary modulus of elasticity (MPa); E_1 = primary modulus of elasticity (MPa).

Results for modulus of elasticity and effective strain – trial I:
- primary modulus of elasticity for the first trial was: E_1 = 20.83 MPa,
- secondary modulus of elasticity for the first trial was: E_2 = 35.16 MPa,
- the effective strain for the first trial was: I_o = 1.69.

Results for modulus of elasticity and effective strain – trial II:
- primary modulus of elasticity for the second trial was: E_1 = 19.23 MPa,
- secondary modulus of elasticity for the second trial was: E_2 = 35.16 MPa,
- the effective strain for the second trial was: I_o = 1.83.

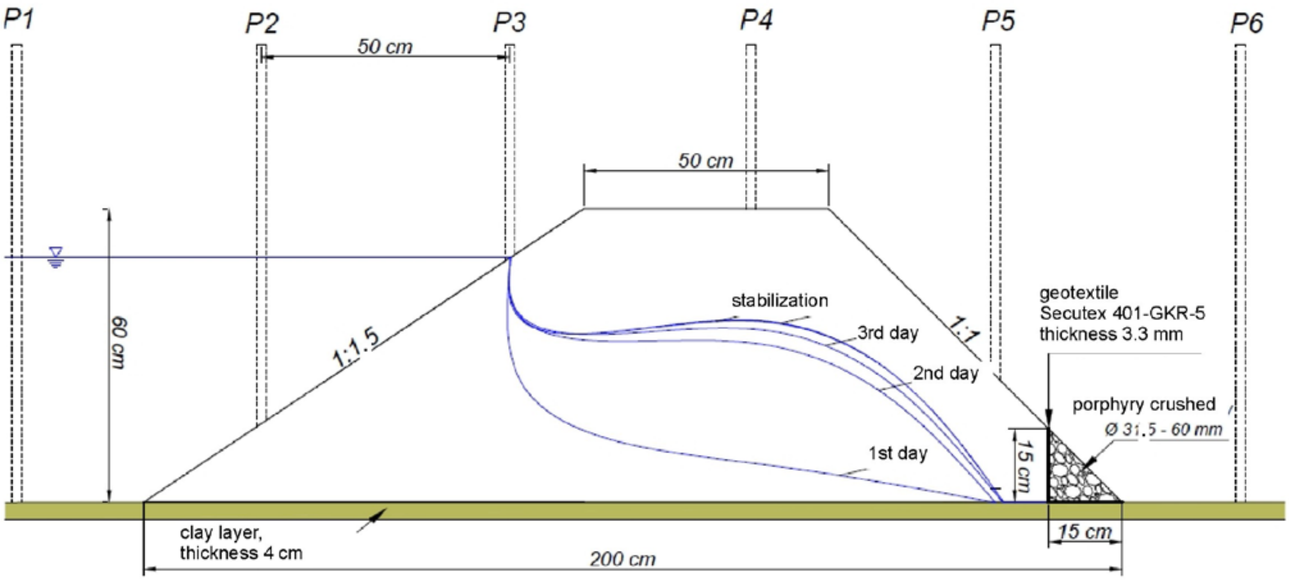

Fig. 2. Location of the water table in particular piezometers during the test and 10 days after damming up of water; source: own study

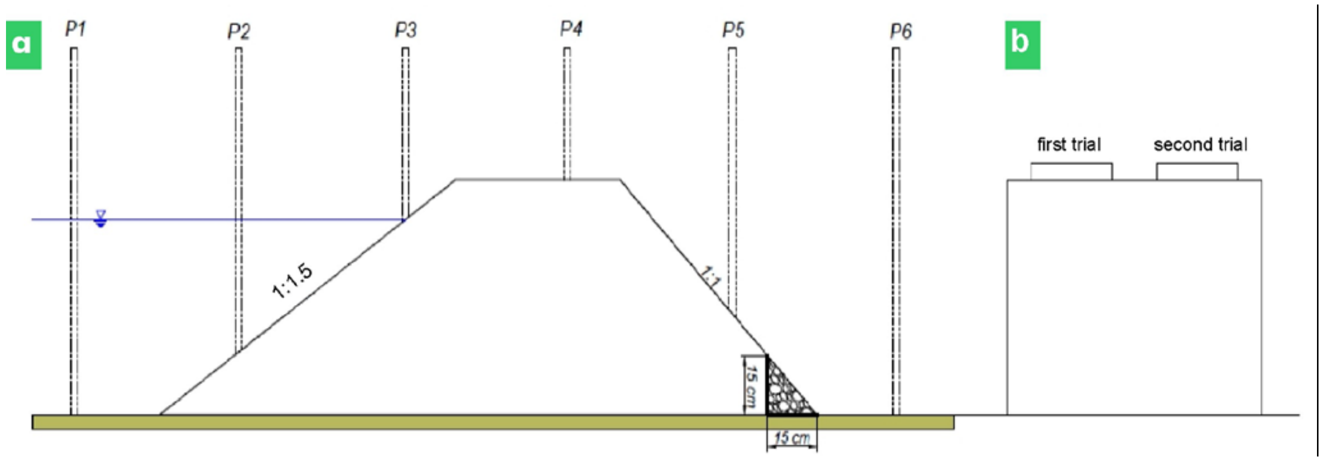

Fig. 3. The experimental embankment, with its cross-section with a marked VSS test site; a) side view, b) view from the landside slope; source: own elaboration

VSS test – the relationship between the deformation of the embankment crown on the set load value

Dependence between the deformation of the embankment crown and the value of applied load was presented in a graphical manner (Fig. 4). In the first trial during the primary load, the total deformation for the embankment under the set primary load value of 0.25 MPa was 3.23 mm. Upon relieving the embankment crown, deformations decreased almost twice to 1.74 mm. After the load is relieved, a secondary load is applied again to the embankment crown, which causes an increase in total deformation (Fig. 4) With the maximum secondary load applied of 0.25 MPa, the total deformation was 3.99 mm. The primary modulus of elasticity after the first load trial was 20.83 MPa and the secondary modulus of elasticity was 35.16 MPa. Effective strain I_o = 1.69.

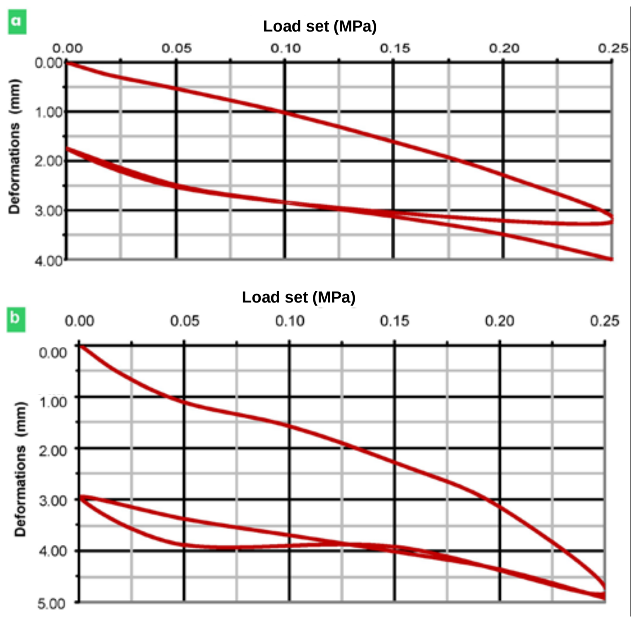

Fig. 4. The relationship diagram between the deformation of the embankment crown on the amount of load set: a) trial I, b) trial II; source: own study

In the second trial, after applying the maximum load of 0.25 MPa, the deformation was 4.83 mm (Fig. 4). This is 1.6 mm more than in the first trial. Once the primary load was relieved to 0.00 MPa, the total deformation decreased to 2.94 mm. Then, the secondary load was applied and an increase in total deformation resulting from the increased load was observed. With the maximum secondary load applied of 0.25 MPa, the total deformation was 4.91 mm. Please note that in the second trial, the total deformation caused by loading was 23% higher than the total deformation in the first trial.

The primary modulus of elasticity for the second load trial was 19.23 MPa and the secondary modulus of elasticity was 35.16 MPa. Effective strain I_o = 1.83.

CHANGE IN THE WATER TABLE IN THE EMBANKMENT DEPENDING ON THE LOAD

A water table constant was maintained for 10 days. Then, the embankment crown loaded with a VSS plate was loaded. During loading, the water table levels in piezometers were observed. To illustrate the relationship we plotted a graph for piezometers P3 and P4 (Fig. 5). These piezometers are closest to the embankment crown (Fig. 3). The load was applied in two trials. Figure 3 shows the location of the trial sites.

In the first trial, as the primary load increased, the water table in both piezometers started to decrease (Fig. 5). After the load of 0.25 MPa was applied, the water table in the P3 piezometer decreased from 43.7 cm to 38.6 cm within 42 min. The water table in the P4 piezometer also decreased from 43.5 cm to 39.2 cm. After primary loading was completed, the load was relieved. During gradual relieving, the water table in both piezometers increased. In the P3 piezometer, the water table rose from 38.6 cm to 41.0 cm. However, in the P4 piezometer, this increase was small, as the water table only rose from 39.2 cm to 39.8 cm. Once relieving ended, the secondary load was applied starting from 0.05 MPa. Once the secondary load achieved the value of 0.25 MPa, the water level in the P3 piezometer decreased again to 39.5 cm. At the same time, the water table level dropped to 38.8 cm in piezometer P4. When the

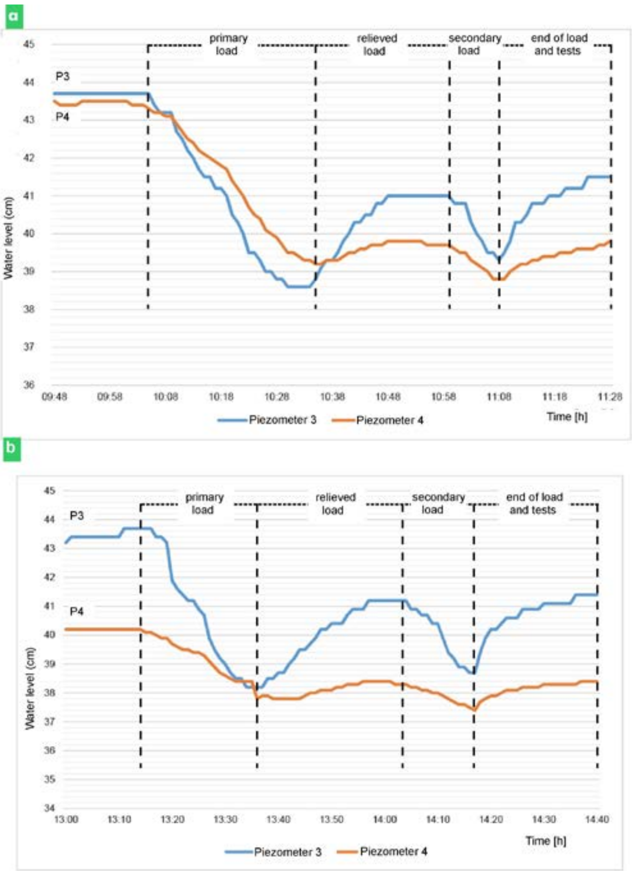

Fig. 5. Changes in the position of the water table in P3 and P4 piezometers during VSS test: a) trial I, b) trial II; source: own study

VSS plate load on the crown was relieved, the water level in the piezometers began to stabilise. After the 20 minutes of the end of the test, the water level in piezometer P3 was 41.5 cm, while in piezometer P4 it was 39.8 cm. After completion of the load and test, the embankment height did not return to its original value.

Readings from piezometers P3 and P4 were also used for the analysis of the second embankment crown load trial (Fig. 5). However, as a result of a load set at 0.25 MPa, the water level in the P3 piezometer dropped to from 43.7 cm to 38.3 cm within 18 min. At the same time, the water level in the P4 piezometer dropped from 40.2 cm to 37.8 cm. As in the case of the first trial, the load was relieved after primary loading was completed. As a result of relieving the piezometer P4 from 37.8 cm to 38.4 cm. After the secondary load was applied, the water table in the P3 piezometer dropped in 20 min from 41.2 cm to 38.7 cm. On the other hand, in the P4 piezometer, the water table dropped from 38.4 to 37.4 cm. After completion of the load and test, the embankment height did not return to its original value.

Based on the analysis performed, we concluded that the load on the embankment crown has a significant impact on the water table in the embankment. Under the influence of the load applied to the embankment crown, the water table level decreases. However, with embankment load decreasing, water table level increases.

CONCLUSIONS

1. The embankment model built from natural soil works well as a structure that keeps damming water in a continuous manner, while drainage shortens the filtration path and thus additionally protects the embankment.

2. The use of drainage in the form of a stone prism at the foot of the landside slope allows protecting the slope against the negative influence of filtration (piping, liquefaction).

3. The average values of primary modulus of elasticity (E_1) and secondary modulus of elasticity (E_2) obtained from two VSS tests: E_1 = 20.03 MPa, E_2 = 35.16 MPa.

4. For repeated loading and relieving cycles, the soil deformation curves were found to be repetitive and parallel to each other, thus some soil elasticity can be assumed.

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