V ENVIRONMENTAL ENGINEERING

ANTI-SEEPAGE MEANS FOR PROTECTIVE EMBANKMENT OF KARIOTIŠKĖS SEWAGE SLUDGE DUMP

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ABSTRACT

The seepage through the protective embankment of the Kariotiškės sewage sludge dump and anti-seepage means for the stopping of seepage are analysed in the article. It was determined that during the closure works of the dump of Kariotiškės it is necessary to ensure (due to the environmental protection requirements) that sludge filtrate should not filtrate through the protective embankment and should not gain access into the surroundings. Having viewed all possible anti-seepage means (drainage, changing of permeable soils into impermeable ones, etc.) as well as the geological situation we came to the conclusion that one of the most effective, economic and simplest ways was the arrangement of hermetic sheet piling.

Keywords: seepage, modelling, Kariotiškės sewage sludge dump, filtration coefficient, sludge filtrate, protective embankment, impermeable shield.

INTRODUCTION

The aim of the Directive is, by way of stringent operational and technical requirements on the sewage dumps (COUNCIL DIRECTIVE..., 2011), to provide for measures, which should help prevent or reduce negative impact on the environment, in particular the pollution of surface water, ground water, soil and air. Whereas it is necessary to indicate clearly the requirements with which sewage dumps must comply as regards location, conditioning, management, control, closure and preventive and protective measures to be taken against any threat to the environment in the short as well as in the long-term perspective, and more especially against the pollution of groundwater by the leaking of the filtrate into the soil.

The object of this article is one of the largest dumps in Lithuania, i.e., the Kariotiškės sewage sludge dump. The dump covers the area of 5.48 ha, the area of mirror surface is 4.80 ha, the maximum depth – 12.0 m, the perimeter of protective embankments – 394 m. It was calculated that approx. 389840 m^3 of sludge were accumulated in the storage.

The objective of this article was to analyse seepage through the protective embankment of the Kariotiškės sewage sludge dump. As the basis for this work, geotechnical investigations over the protective embankment of the Kariotiškės sewage sludge dump (carried out by CJSC "Geotechniniai tyrimai") were used as well as geotechnical cross-sections of the protective embankment were created.

The altitudes of the crest of the protective embankment of the Kariotiškės sewage sludge dump are 172.6…172.9, and those of the base of the embankment – 167.4...169.3. The crest width of the protective embankment is approx. 2.5 m, and its slope sinks at a 32^o angle on the average (in some cross sections the slope sinks even at a 45^o angle on the average). Landslides have formed in some places of the protective embankment of the Kariotiškės sewage sludge dump. Cracks have formed on the top of the embankment (along the embankment). One can observe water seepage, slope wash and landslides in some places of the protective embankment.

The protective embankment of the Kariotiškės sewage sludge dump consists of technogenical soil (bulk soil – dusty clay and sand with additives consisting of demolition waste, domestic rubbish and organic materials). The bottom of the Kariotiškės sewage sludge dump consists of glacial and fluvioglacial landforms (moraine sandy, dusty clay, gravely sand and dusty sand) and swamp sediments (peat).

The thickness of the bulk soil is 5.4…7.0 m above the centre of the embankment and it decreases up to 2.1…3.8 m at the foot of the embankment. The major part of the embankment consists of medium-hard and hard dusty clays interstratifying with the weaker ones – soft plastic or hard plastic dusty clays, mellow and medium dense sands. Clay soils naturally lie under the embankment of the bulk soil, which stratify from 164.5 up to 167.4 altitudes. The thickness of the soil layers of the base of the embankment was not determined.

In the analysed primary data it was not fixed that the ground water was in the depth of 1.8…7.0 m from the ground surface (altitude 165.5…168.8). The water occurs in the seams of the bulk sand, peat layers as well as in the aquiferous sand streaks situated in moraine sandy and dusty clays. In some places of the protective embankment one can observe water seepage, slope wash and landslides.

The most important seepage parameter – filtration coefficient – was not defined for the singled out geological soil layers.

METHOD

The available data show (UAB „Geotechniniai tyrimai", Kariotiškių nuotekų dumblo sąvartyno uždarymas. Nuotekų ..., 2009; UAB „Geotechniniai tyrimai", Kariotiškių nuotekų dumblo sąvartyno uždarymas. Dumblo ..., 2009) that the seepage (through the protective embankment of the Kariotiškės sewage sludge dump) can occur from the sewage sludge into the swamp situated below. According to the environment protection requirements, the filtrate from the sludge dump should not gain access into the surroundings. The waste sludge filtrate can gain access into the surroundings, when the protective sheet is not arranged (or is damaged) in the slopes and (or) the bottom of the Kariotiškės sewage sludge dump. There are no data on the arrangement and functioning of the protective sheet. There is no any available design documentation over the arrangement of the protective sheet while arranging the Kariotiškės sewage sludge dump.

At present, closure works of the Kariotiškės sewage sludge dump are being carried out. It should be ensured that the waste sludge filtrate should not gain access into the surroundings and should not pollute it. The project of the Kariotiškės dump was prepared in 1981-1983, the dump was built in 1984-1986 and the exploitation of the dump started in 1987. Not much attention was paid to the environment protection and job fulfilment quality then, therefore, the protective sheet for the sewage sludge dump could not be arranged at all.

The seepage through the protective embankment was analysed when carrying out the numerical modelling of the seepage. The numerical modelling of the seepage was carried out in the cross sections I-I, II-II, III-III and IV-IV (made by CJSC "Geotechniniai tyrimai") of the protective embankment (Fig. 1), in which the soil layers were singled out and the geotechnical characteristics of some soils were defined. The modelling was carried out using the computer seepage modelling program Geostudio Seep/W 2007 (Geostudio ..., 2011).

The seepage modelling consists of four inter-connected parts: the creation of the numerical model, the mathematical solution of this model, the analysis of the results and the calibration of the mathematical model. Creating the numerical model of the analysed territory the schematised environment of the seepage as well as the geological, hydrogeological, topographical and some other factors influencing the process of the seepage are being expressed in numbers. Since the modelled territory is not borderless and has boundaries, it is very important to correctly define and depict the marginal conditions. The mathematical solution of the created numerical modelling is being carried out while solving differential equations (depicting mathematical groundwater movement model) by mathematical methods. The received results are compared with natural investigations or data and, if necessary, the calibration of the created numerical model is being carried out.

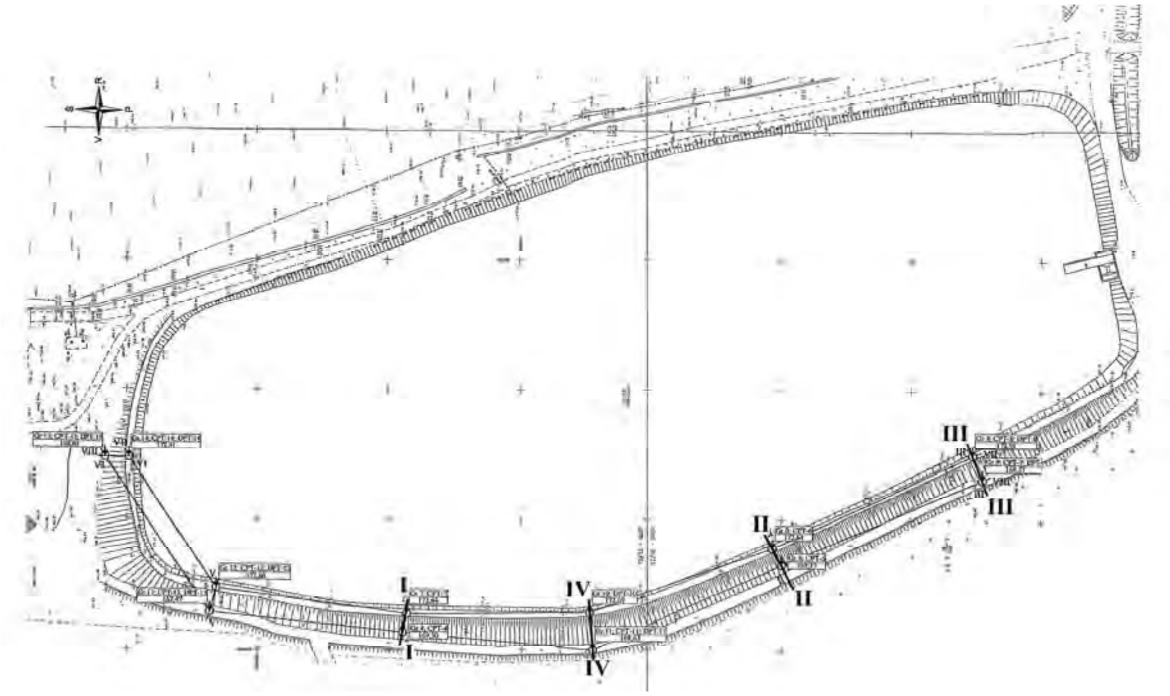


Fig. 1. Places of the geotechnical cross-sections in the protective embankment of the Kariotiškės sewage sludge dump.

The creation of the seepage model of the analysed territory is the stage of modelling requiring much work, time and professional knowledge. The more precisely the numerical model will correspond to the real situation, the more precise and reliable modelling results will be. The precision of the calculated seepage parameters depends upon the precision of the primary data and their correspondence to the real situation, therefore, reliable primary data (which are determined by natural investigations) are necessary for the modelling of the seepage tasks. The permeability of soils is depicted by the filtration coefficient k (Craig, 1995; Todd et al., 2005; Ухов et al., 2004) when analysing and modelling seepage. When there are no determined filtration coefficients of soils, they are chosen considering the known geological characteristics of soils (Dobkevičius, 2001; Verrujit, 2006; Далматов, 1988) and generalized filtration coefficients (presented in literature) of different types of soils (LST 1445, 1996; STR 1.04.02:2004, 2004). The filtration coefficients are presented in Table 1.

It should be noted that only possible limits of variation of the filtration coefficients of different types of soils are presented in literature, therefore, the chosen particular values of the filtration coefficient can differ from the ones existing in nature (Pocius, 1996; Šimkus et al., 1973; Морарескул et al., 1979). The values of the filtration coefficients of soils depend upon many factors, such as the granulometric and mineral composition of soils, density, structure and texture, amount of additives as well as upon the chemical composition and temperature of ground water, therefore, the chosen filtration coefficients of soils can differ from the natural ones (Pranaitis et al., 1979; Šimkus, 1984; Тер-Мартиросян, 1990).

The boreholes, according to which the soils were singled out and their geotechnical parameters were defined, were bored on top of the protective embankment and at the foot of the dry slope. It gives a sufficiently comprehensive view on the soils forming the protective embankment, but it does not provide us with comprehensive information over the natural soils existing under the protective embankment, especially those existing under the wet slope of the embankment and the bottom of the dump. Without the sufficient primary simulation data the seepage is modelled only through the protective embankment of the Kariotiškės sewage sludge dump.

It should be noted that according to the data received from the CJSC "Geotechniniai tyrimai", naturally stratified layers of moraine clay predominantly lie under the protective embankment (above its dry slope). According to the literature data, clay soils are considered less permeable or practically impermeable soils. The permeability of moraine clay soils is even up to 10^{10} less than the one of permeable sandy soils. Moraine clay soils are used when arranging impermeable insulating substrata (sheets), therefore, seepage of the sludge filtrate from the sludge dump through the layers of moraine clay is practically impossible.

ANALYSES OF MODELLING RESULTS

Four seepage numerical models were made in the cross-sections I-I, II-II, III-III and IV-IV of the protective embankment (Fig. 1).

The aim of the modelling was the final results of the stable seepage, the main seepage parameters used in the modelling did not vary, and, therefore, the unconfined stable seepage was modelled. Besides, the possible errors of choosing of the filtration coefficients of soils when modelling stable seepage (when the coefficients of seepage of soils were not defined by field and laboratory experiments, they were chosen according to the literature data) had less impact upon the accuracy of the modelling results than when modelling unstable seepage.

Table 1

Filtration coefficients of soils

Nr.	Types of soil	Soil consistency and density	The coefficient of filtration *k* of soil *m/day*
1	Bulk soil: dusty clay	Soft plastic	0.01
2	Bulk soil: dusty clay	Hard plastic	0.01
3	Bulk soil: dusty clay	Medium hard	0,01
4	Bulk soil: dusty clay	Hard	0.01
5	Bulk soil: sand	Mellow	30
6	Bulk soil: sand	Medium dense	15
7	Peat	Medium and well decomposed	1.0
8	Dusty sand	Dense	5
9	Moraine sandy dusty clay	Dense plastic – soft plastic	0.0001
10	Moraine sandy dusty clay	Hard plastic	0.0001
11	Moraine sandy dusty clay	Medium hard	0.0001
12	Moraine sandy dusty clay	Hard	0.0001
13	Gravelly sand	Dense	50
14	Dusty sand	Dense	5

When creating the numerical models of seepage the level of sludge in the dump and the potential limits of the seepage of the sludge filtrate, the dry slope of the protective embankment and the swamp at the foot of the embankment, were defined by boundary conditions. According to the presented primary data, the altitude of the dump filling with sludge was accepted as 171.6 and set as the first boundary condition – the fixed water level *H (H=171.6)*. The dry slope of the protective embankment and the swamp at the foot of the embankment were accepted as the second boundary condition – discharge flowing through the boundaries *Q* $(Q=0\ m^3/s)$. Such a creation of the model and the acceptance of the boundary conditions allowed modelling and analysing seepage from the sludge dump. The coefficients of seepage of the geological layers of the created models were set according to the accepted values (Table 1). In default of the presented data, precipitation and evaporation were not estimated in the process of seepage modelling.

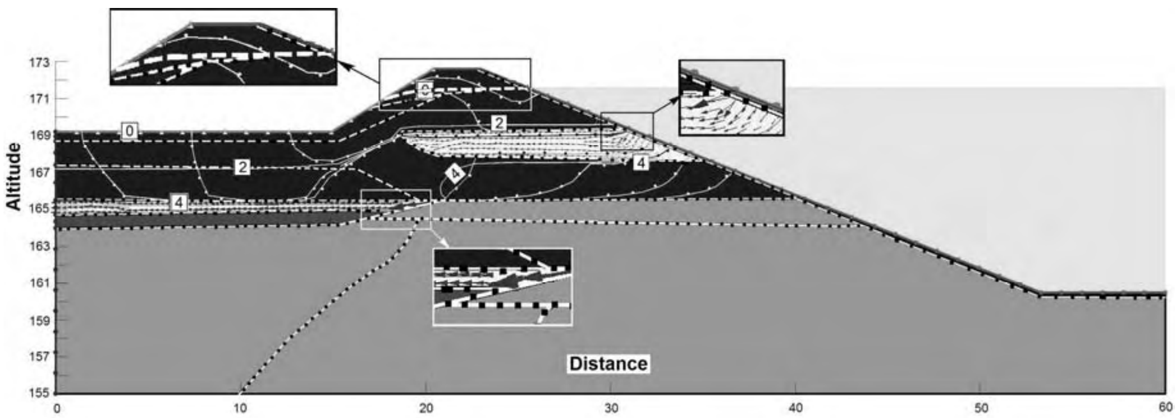
As it was mentioned before, the seepage of the filtrate from the sludge dump into the swamp situated behind the protective embankment can occur if the protective sheet of the sludge dump is not arranged or is damaged. Since there are no data concerning the protective sheet and there is no available design documentation over the arrangement of the protective sheet (during the arrangement of the Kariotiškės sewage sludge dump), the potentially worst possible variant was chosen – the protective sheet was not arranged at all and did not limit the seepage from the sludge dump.

Calculations of the created seepage models are being carried out using the finite element method. For achievement of the modelling accuracy, irregular elements, such as quadrangulars and triangles ensuring the correspondence of the model to nature, are chosen. The size of the boundary of the elements is accepted not larger than 0.3 m during the seepage modelling, thus partitioning the numeric models into more or less 9000-10000 finite elements and ensuring the accuracy of the modelling.

The curve of depression, isolines of hydrostatic pressure, vectors and flow lines of the ground water flow are the modelling results. The curve of depression shows the surface of ground aquifer. In this surface, the hydrostatic pressure (rejecting the atmospheric pressure) is equal to zero. Going deeper, this pressure increases. The lines of hydrostatic pressure above the curve of depression can be explained in the following way: aeration zones were estimated during the modelling. The ground water flow vectors show the intensity of the water flow. The velocity of the ground water flow is the largest in such places, where the vector arrows are the longest and, vice versa, the velocity of the ground water flow is the smallest, where the vector arrows are the shortest. The number of the vector arrows of the velocity of the ground water flow shows the intensity of the ground water flow. The flow lines show the directions and lines of the separate ground water flows (separate water particles) in the common seepage flow. The example of the modelling results is presented in Fig. 2.

Analysing the modelling results we see that with the absence or damage of the sheet seepage occurs (through the protective embankment of the Kariotiškės sewage sludge dump) from the sewage sludge into the swamp situated below. Following the modelling results we see that most intensively the seepage occurs through permeable sandy soils.

The seepage modelling results of the protective embankment show that the curve of depression (ground water level) will match the ground surface at the foot of the embankment when seepage is stable.



- depression curve; 2 - isolines of hydrostatic pressure; - ground water flow vectors; - flow lines

Fig. 2. Seepage modelling results of the section I-I in the protective embankment of the Kariotiškės sewage sludge dump.

In three of four cross-sections (II-II, III-III and IV-IV) the depression curve comes up into the ground surface in the dry slope of the embankment and can be the reason for water seepages and landslides in the slope. Following the environmental protection requirements the filtrate from the sludge dump should not gain access into the surroundings, therefore, means for stopping the seepage are necessary.

Having viewed all the possible anti-seepage means (drainage, changing of permeable soils into impermeable ones, etc.) as well as the geological situation we came to the conclusion that one of the most effective, economic and simplest ways was the arrangement of hermetic sheet piling (Ruplys, 1988; Ренгач, 1970). Following the report over the soil geotechnical investigations of the protective embankment and the foot of the embankment of the Kariotiškės sewage sludge dump one can see that in some places the protective embankment is arranged on permeable soils, through which seepage of sludge filtrate from the sludge dump can occur. In order to prevent the seepage through the protective embankment and permeable layers, especially during the closure works of the sludge storage, when the distributed load will be put and the filtration velocity will increase, it is purposeful to arrange hermetic sheet piling (when sinking it through permeable soils up to practically impermeable moraine clay soils). Thus the arrangement of the hermetic sheet piling will double the effect, i.e., will stop the seepage through the protective embankment and block up (lock) permeable layers of the natural soil.

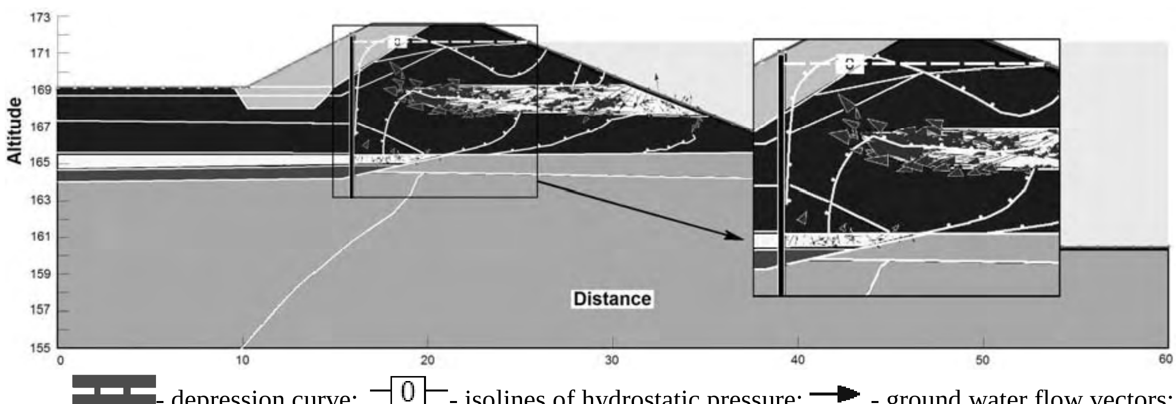
In order to evaluate the influence of the hermetic sheet piling upon the seepage from the Kariotiškės sewage sludge dump, the numerical models of the four cross-sections I-I, II-II, III-III and IV-IV were created. The geotechnical characteristics of soils in the created seepage models are analogical to the earlier created models. The altitude of the dump filled with sludge is accepted as the first boundary condition – the fixed water level *H* $(H=171.6)$, the dry slope of the protective embankment and the swamp situated at the foot of the slope are accepted as the second boundary condition – discharge flowing through the boundary *Q* $(Q=0\ m^3s)$, precipitation and evaporation were not estimated in default of the data.

The modelling of the seepage was carried out when accepting potentially the worst variant, i.e., when the protective shield was not arranged. The seepage calculations were carried out using the finite difference method when partitioning the numeric models into more or less 9000-10000 finite elements and thus ensuring accuracy of the modelling results.

The modelling results consist of the curve of depression, isolines of hydrostatic pressure, vectors and flow lines of the ground water flow. The example of the modelling results is presented in Figure 3.

Analysing the results of the seepage modelling (when the hermetic sheet piling is arranged) we see that the seepage through the protective embankment of the Kariotiškės sewage sludge dump will be stopped and the sludge filtrate should not gain access into the swamp situated at the foot of the embankment. The arrangement of the hermetic sheet piling (when sinking it through permeable soils up to practically impermeable moraine clay soils) stops the seepage through the protective embankment of the Kariotiškės sewage sludge dump and locks the natural layers of the permeable soil situated beneath the embankment.

The arrangement of the hermetic sheet piling is the most efficient and optimal anti-seepage means due to the blocking of permeable layers. Hermetic sheet piling increases the stability of the protective embankment as well and is easy to arrange.



- depression curve; 0 - isolines of hydrostatic pressure; - ground water flow vectors; - flow lines

Fig. 3. Seepage modelling results with hermetic sheet piling of the section I-I in the protective embankment of the Kariotiškės sewage sludge dump.

The bottom of the sheet piling should be sunk into hard and medium hard plastic moraine clay soils occurring beneath permeable soils. It should ensure its static stability.

CONCLUSIONS

1. In order to ensure the environment protection requirements when carrying out the closure works of the Kariotiškės dump, the geological situation and possible anti-seepage means blocking sludge seepage through the protective embankment were analysed. It was defined that in default of the damaged protective sheet the filtrate from the sludge dump can gain access into the surroundings, i.e., can filtrate into the swamp situated at the foot of the embankment.
2. The modelling of the seepage of the Kariotiškės sewage sludge dump was carried out. Following the analysis of the received results it was defined that:

- seepage most intensively occurs through permeable sandy soils; through less permeable clay soils it is much more slower;
- in three of four cross-sections (I-II, III-III and IV-IV) the depression curve comes up into the ground surface in the dry slope of the embankment and can be the reason for water seepages and landslides in the slope.

3. The suggested arrangement of hermetic sheet pilings (deepened into the naturally stratified impermeable layers of moraine clay) is one of the most efficient, economic and simplest ways stopping the seepage of the sludge dump filtrate through the protective embankment as well as through the blocked layers of the protective embankment.
4. The analysis of the carried out modelling results showed that the hermetic sheet piling showed the best result as anti-seepage means. Besides, it increases the stability of the protective embankment.

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