ISSN 1864-6168
UDK 62

GEOTEHNIČKE KARAKTERISTIKE PRIRODNOG MATERIJALA ZA UGRADNJU U BRTVENE SLOJEVE NA ODLAGALIŠTU OTPADA

GEOTECHNICAL CHARACTERISTICS OF NATURAL MATERIAL USED FOR INSTALLATION IN LANDFILL SEALING SYSTEMS

Marina Hrnčić, Nikola Hrnčić, Filip Dodigović

Stručni članak

***Sažetak**: U radu se razmatra važnost geotehničkih parametara tla koji su ključni element pri odabiru prirodnog materijala koji se ugrađuje u brtvene slojeve odlagališta otpada. Brtveni slojevi su dio brtvenog sustava odlagališta, koji se u pravilu sastoji od više slojeva različitih debljina, namjene i materijala za njihovu izvedbu. Najvažniji dijelovi brtvenog sustava su svakako brtveni slojevi za čiju se izgradnju koriste prirodni ili umjetni materijali. Zbog svoje visoke nepropusnosti, prirodni, glinoviti zemljani materijali su se pokazali kao naročito pogodni te se kao takvi danas i najčešće koriste za ugradnju u brtvene slojeve. Koeficijent vodopropusnosti, optimalna vlažnost, zatim stupanj zbijenosti i modul stišljivosti takvog prirodnog odnosno zemljanog materijala osnovni su i najvažniji elementi koje je nužno ispitati jer upravo o tom segmentu ovisi sigurnost i trajnost svakog suvremenog odlagališta otpada.*

***Ključne riječi:** brtveni sustav, glineni brtveni sloj, geotehnički parametri tla, odlagalište*

Professional paper

***Abstract:** This paper describes the importance of geotechnical soil parameters which are the key element to consider in the selection of natural material that will be installed in the landfill sealing layers. Sealing layers are part of the landfill sealing system which usually consists of more layers with different thickness, purpose and material of their construction. The most important parts of the sealing system are definitely the sealing layers which can be built with natural or artificial materials. Due to its high imperviousness, natural clay materials have been proven as especially suitable and today are the most commonly used material for installation in the sealing layers. Hydraulic conductivity, optimal moisture content, compression index and compression modulus of such natural i.e. soil material are the most important elements which have to be tested since the safety and durability of every modern landfill relies exactly upon them.*

***Key words:** sealing system, clay liner, geotechnical parameters of soil, landfill*

1. INTRODUCTION

The most important parts of every landfill are sealing layers and the filtrate drainage system.

The landfill sealing system has to be adapted to real conditions and needs of the location, i.e. the type of disposed waste.

Sealing layers are parts of the system that prevent the penetration of precipitation and other water into the landfill, as well as filtrate spreading from the landfill into the aquifer [1], and are divided into:

- the base sealing layer that represents a barrier between the landfill and the natural subgrade soil (figure 1)
- the final cover sealing layer that covers the waste and prevents precipitation water from penetrating into the landfill (figure 2)

Sealing layers consist of mineral or artificial material, whose selection has to meet certain technical, technological and economical criteria.

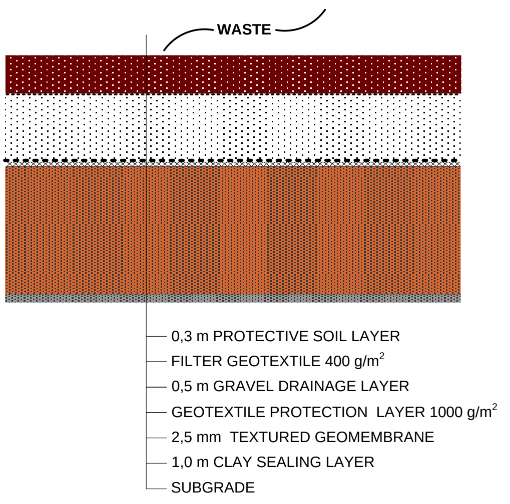

Figure 1. Base sealing system

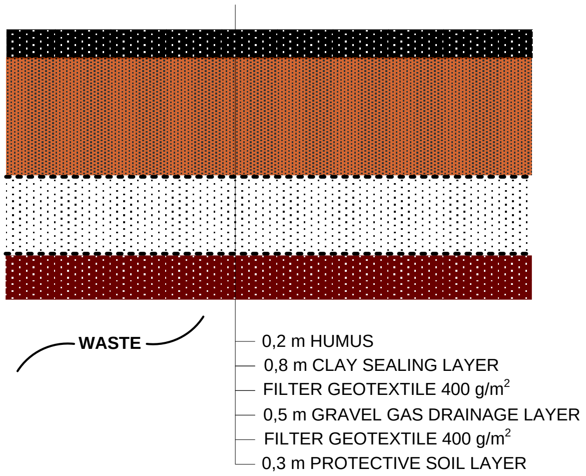

Figure 2. Final cover sealing system

1.1. Generalities about the selection criteria of sealing layers materials

A sufficiently reliable sealing system depends on the material that is going to be used for the construction of sealing layers and on special conditions that are determined by previous experience, so it contains the following:

- hydraulic conductivity as defined by regulations (k)
- stability, i.e. durability in exploitation conditions (to the temperature of at least 70°C, substances contained in waste, waste gases and leachate water, landfill load, erosion, freezing, subgrade settlement etc.)
- technical and technological suitability for installation
- the possibility of controlling the imperviousness (during the construction, exploitation (filling) and resting after the landfill is closed)
- imperviousness to gases released from the landfill
- the possibility of renewing damaged and "fatigued" material
- market competitiveness (cost-effectiveness)

Regarding the aforementioned criteria, the most commonly used natural material installed in sealing systems is clay. Clay quality control, especially regarding its imperviousness, is carried out by standard procedures common for testing materials installed in sealing barriers. The only difference relates to the criteria that have to be met by clay, which result from local construction conditions and the required insulation potential.

2. IMPORTANT GEOTECHNICAL SOIL PARAMETERS

The quality of clay installed in every single layer of the final cover and base sealing layer and its compaction are controlled by certain types of laboratory and "in situ" testings. The most important geotechnical soil parameters tested are: hydraulic conductivity, optimal moisture content, compression index and compression modulus.

2.1. Hydraulic conductivity *k*

Hydraulic conductivity is one of the key indicators for determining the quality of sealing layers, so a special attention is to be paid to it.

The issue of sealing layer imperviousness is treated within the criteria for achieving the maximum compaction of cohesive soil. This criterion is to be specially modified, taking into account the required maximally allowed hydraulic conductivity of a sealing layer. The possibility of efficient measurement of hydraulic conductivity of cohesive materials is very important, both in the laboratory, as well as in the field [3].

Darcy's law, which is valid only for laminar water flow in pores, defines the hydraulic conductivity as the relation between the percolation velocity v and hydraulic gradient i according to expressions (1), (2) and (3).

$$k = \frac{v}{i} \tag{1}$$

$$v = \frac{q}{A} \tag{2}$$

$$i = \frac{\Delta h}{L} \tag{3}$$

v – fictive velocity of water flow (m/s)
q – flow rate (m^3/s)
A – surface of soil through which water flows (m^2)
i – hydraulic gradient (1)
Δh – difference between the water level at the entry and exit from the observed soil sample (m)
L – length of the water pathway through the soil (m)
k – hydraulic conductivity (m/s)

Hydraulic conductivity is the soil constant that depends on the geometry and width of voids between solid particles through which water flows, which depends on the soil type tested and the fluid viscosity. Figure 3 shows the relation between the hydraulic conductivity k and the void ratio e.

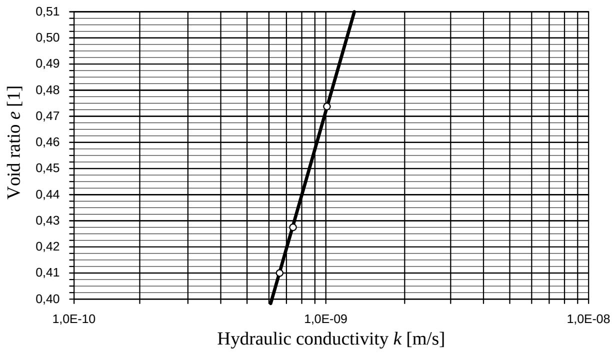

Figure 3. Relation between k and e

2.2. Optimal moisture content (w_{opt})

The optimal, most adequate soil moisture content w_{opt} is the one that, along with certain compaction energy consumption, results in the greatest compaction, i.e. the highest dry unit weight γ_d.

Along with the optimal moisture content w_{opt}, the most adequate degree of saturation $S_{r_{opt}}$ for the compaction of soil is obtained, according to the following expression (4).

$$S_{r_{opt}} = \frac{\gamma_s \cdot \gamma_d}{(\gamma_s - \gamma_d) \cdot \gamma_w} \cdot w_{opt} \tag{4}$$

γ_s – unit weight of solids (kN/m^3)
γ_d –dry unit weight of soil (kN/m^3)
γ_w –unit weight of water (kN/m^3)
w_{opt} – optimal moisture content (%)

The values of w_{opt} and γ_d are obtained by the standard Proctor test. Dry unit weight of soil γ_d has the unit weight of solids γ_s, while soil before drying has moisture content w and degree of saturation S_r, as shown in the following expression (5).

$$\gamma_d = \frac{\gamma_s \cdot \gamma_w \cdot S_r}{\gamma_s \cdot w + \gamma_w \cdot S_r} \tag{5}$$

γ_s – unit weight of solids (kN/m^3)
γ_d – dry unit weight of soil (kN/m^3)
γ_w – unit weight of water (kN/m^3)
S_r – degree of saturation (%)
w – moisture content (%)

Dry unit weight is an indicator of compaction, while strength and deformability depend on the soil compaction.

The amount of work necessary for compacting a soil material, in order to achieve certain unit weight, depends on moisture content. The higher the moisture content is, the lower the resistance to mutual particles movement is, i.e. the cohesive strength of soil fragments is lower. As moisture content and compaction work increase, the saturation of voids with water rises, while at high moisture content the saturation is almost total. The moisture content at which the highest dry density ρ_d is achieved is taken as the optimal moisture content w_{opt}.

2.3. Determining the compression index S_z and compression modulus M_s

The compression index S_z is determined in relation to the standard Proctor test, while the compression modulus M_s is obtained by using a circular load plate with a diameter of 30 cm (depending on the material type). At least one test per each 1000 m^2 of installed soil is carried out [2].

Correctly performed compaction has a significant impact on the quality, i.e. durability and safety of construction. Compaction increases the load bearing capacity and stability of soil, decreases perviousness and minimizes soil settlement differences.

Specimens are prepared in the laboratory according to the Proctor principle. Imperviousness is measured using a computer-controlled device for triaxial shear based on the constant rate of flow method. Specimens are consolidated in a triaxial cell, and their saturation is assured by means of back pressure.

Compression index S_z is determined based on the relation between the unit weight of the installed material γ and unit weight after the Proctor test $\gamma_{Proctor}$ according to the expression (6).

$$S_z = \frac{\gamma}{\gamma_{Proctor}} \tag{6}$$

S_z – compression index (%)
γ – unit weight of the installed material (kN/m^3)
$\gamma_{Proctor}$ – unit weight after the Proctor test (kN/m^3)

The compression modulus determines the load bearing capacity of natural or improved soil, and it is also used for controlling the quality of load-bearing layer compaction. It is determined by loading of the tested surface with increasing pressure, using the circular plate of defined dimensions and monitoring soil settlement caused by it. It is calculated according to the following equation (7).

$$M_s = \frac{\Delta p}{\Delta s} \cdot D \tag{7}$$

Δp – difference between two loads (kN/m^2)
Δs – corresponding settlement difference (m)
D – diameter of the circular plate (m)
M_s – compression modulus (kN/m^2)

By defining the compression index S_z and the compression modulus M_s relevant criteria for the evaluation of soil quality are obtained.

Tables 1 and 2 present the data on the aforementioned criteria in relation with the soil material type.

Table 1. Criteria for cohesive soil quality evaluation*

	S_z, minimum (%)	M_s, minimum (MN/m^2)
Compacted soils composed of cohesive soil materials; designed embankment is not higher than 2.00 m	97	20
Compacted soils composed of cohesive soil materials; designed embankment is higher than 2.00 m	95	20

* a part of the material is in the "C" excavation category- all clay materials of low to high plasticity and silty soils

Table 2. Criteria for noncohesive soil quality evaluation*

	S_z , minimum (%)	M_s , minimum (MN/m^2)
Compacted soils composed of noncohesive and mixed soil materials; designed embankment is not higher than 2.00 m	100	25
Compacted soils composed of noncohesive and mixed soil materials; designed embankment is higher than 2.00 m	95	25

*materials of the excavation categories “A” and “B”, a part of the material is in the “C” excavation category, rocky materials, mixed rocky and soil materials, clayey gravels, clayed crushed stone, flysch sandstones, dolomites, schists, conglomerates, sands, sandy gravels

It is necessary that the tested material is of optimal moisture content in order to avoid obtaining inaccurate results. Therefore, moisture content of the tested ground is determined before initiating the test. The surface at the test spot has to be graded, completely flat and protected from humidity or drying [2]. Circular load plate is placed onto the prepared spot. Using a leveling instrument it is checked whether it is laid horizontally (figure 4). The plate is first loaded with 0.02 MN/m^2, the loading is held for a minute and then the plate is unloaded. The first load amounts to 0.05 MN/m^2 and, after it is reached, the stopwatch is turned on and simultaneously the settlement of the plate is recorded.

Figure 4. Static load plate

The settlement is recorded after the first, second, third etc. minute, until it is lower than 0.05 mm in the last two minutes. After that the load increases gradually, each time by 0.05 MN/m^2 until it reaches the final load amounting to 0.45 MN/m^2 [2].

3. CONCLUSION

The selection of materials and preciseness in the construction of sealing systems are of vital importance for avoiding mechanical damage, landfill settlement or protective foil damage in the base sealing, at which a special attention is to be paid to sealing layers. The quality of material installed into them is to be precisely tested at assessing its suitability for installment and after the installment, because the final cover sealing layer has to completely prevent precipitation water from penetrating into the body of the landfill, while the role of the base sealing layer is to prevent the filtrate from leaking out from the body of the landfill. For the purpose of achieving and maintaining the required quality, especially regarding the imperviousness of sealing layers, laboratory and "in situ" tests of natural (soil) material are conducted, at which the most important geotechnical parameters of such soil, i.e. clay, are: hydraulic conductivity, optimal moisture content, compression index and compression modulus.

Sufficiently low hydraulic conductivity k is the initial and key indicator of clay quality at assessing its suitability for installment. As previously mentioned, achieving suitable imperviousness of a material is treated within the criteria for reaching the maximum compaction. Therefore, sufficient and correctly performed compaction not only increases the load bearing capacity and stability of soil, but it also increases its imperviousness. Compaction quality is controlled by determining the compression index S_z and compression modulus M_s of the installed clay. Compression index testing is carried out at a laboratory, in relation to the standard Proctor procedure, while the compression modulus is determined "in situ", usually by loading a load plate of a suitable diameter and by measuring the settlement of the installed soil. As it is known from the geotechnical practice, the highest compaction, and thereby the imperviousness of the installed clay, are achieved by its compaction at the optimal moisture content w_{opt}, which by all means should be assured for the clay material during the compaction process.

4. REFERENCES

[1] Samokovlija Dragičević J.: Uvjeti za gradnju odlagališta otpada, Građevinar, Vol. 62, No. 4 (2010) 345-351

[2] Glavni projekt uređenja postojećeg odlagališta otpada "Piškornica" – Koprivnica: IGH d.d., Zagreb, 2004

[3] Kvasnička P., Gjetvaj G., Verić F., Matešić L.: Svrhovitost ispitivanja fizikalnih svojstava mineralnih brtvenih i drenažnih slojeva kod odlagališta otpada, IV. International symposium: Gospodarenje otpadom - Zagreb '96, Zagreb, 1996, 308-322

Contact:

Marina Hrnčić, dipl.ing./graduate engineer
Hrvatskih branitelja 6b, Varaždin
marina_banic@yahoo.com

Nikola Hrnčić, dipl.ing./graduate engineer
At consult d.o.o.
Đ. Sudete 8, Varaždin
nikola.hrncic@gmail.com

Filip Dodigović, dipl.ing./graduate engineer
Prokon d.o.o.
Varaždinska 13, Jalkovec
filip.dodigovic@gmail.com