Industrial sludge deposit using geosynthetics Experimental research and case study

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ABSTRACT: For a commercial society producing wire and related products, it was necessary to design a landfill for the technologic residues and for the sludge produced after the technological water treatment. The resulted sludge is centrifuged before storage and it contents heavy metals, metals and other chemicals with high contamination risk. The paper presents the experimental program carried out in order to characterize the sludge and its behavior. The technical solution adopted for the landfill uses geosynthetics materials for the liner (geomembrane) and for the drainage system (geocomposites). The paper also describes some tests performed on drainage geocomposites in contact with the sludge.

1 INTRODUCTION

In order to build a new landfill for the technologic residues and those derived from the water treatment plant of a wire factory, an experimental program was needed in order to characterize the material to be stored, to determine its specific properties and to choose the adapted solution for the landfill.

The landfill is supposed to have two compartments, the first one devoted to solid inert waste, rubble and slag resulted from the technologic process and the second one for the galvanic sludge. The first compartment does not need special protection for the ground, the materials being inert.

The sludge produced after the technologic water treatment, which will be stored in the second compartment, has an important content in heavy metals, so a special liner system has to be installed.

The site of the future landfill is characterized by precipitation greater then the multiannual values for the rainy months and winds with an average speed of 5.5 – 5.8 m/s.

The residue resulted from the water treatment plant, in its initial form, is a suspension with low solid particle content, called sludge. Before the storage, it is dehydrated by centrifugation, obtaining a paste called dehydrated sludge.

The paper presents the experimental laboratory program carried out at the Technical University of Civil Engineering Bucharest and the solution proposed for the landfill.

2 EXPERIMENTAL LABORATORY PROGRAM CARRIED OUT ON THE SLUDGE

The experimental program performed in the Technical University of Civil Engineering laboratories comprised two test types: geotechnical tests on dehydrated sludge and chemical analyses for the sludge, the dehydrated sludge and for the water resulting after the treatment.

2.1 *Geotechnical tests*

The geotechnical tests carried out in order to identify and characterize the dehydrated sludge were the following:

- identification and classification tests (grain size distribution, specific weight, moisture content, Atterberg limits, permeability, free swelling);
- mechanical tests (compressibility, shear strength)
- special tests (erodability to water and wind).

The visual observations led to the following conclusions:

- at rest, the sludge sediments very quickly;
- at the room temperature, the uncovered samples of dehydrated sludge are drying in about 10 – 12 h, forming a scab in surface;
- the solid particles represent about 88% of the dehydrated sludge total volume;
- dried at 105°C, the sludge becomes compact and forms boulders. The dry sludge is friable.

2.1.1 *Identification and characterization tests*

The granulometric composition of the dehydrated sludge is corresponding to silts, but the specific weight of the skeleton is higher then normal for silts, γ_s = 27.07 kN/m^3.

After the centrifugation, the sludge has a moisture content of 27.5 – 28 %, a specific weight γ = 18.93 kN/m^3 and a porosity, n = 45.2%, being practically saturated (S_r = 0.94).

The sludge does not exhibit plastic behaviour, the water being easily separated from particles.

The free swelling tests showed also no interaction between the particles and the water, no swell being noticed.

The permeability coefficient is k = 1.2 – 1.9 $\times$ 10^{-}4 cm/s.

2.1.2 *Mechanical tests*

The classical edometric tests showed an edometric modulus $M_{200\text{-}300}$ = 20 000 kPa which classifies the dehydrated sludge in the group of soils with medium to low compressibility (according to the Romanian norm STAS 1243-88).

In order to determine the shear strength parameters were performed direct reversible shear tests, UU type, with 2 mm/min shear rate. The peak values of the shear strength parameters are ϕ = 37°, c = 17 kPa and the residual ones ϕ_r = 22°, c_r = 31kPa.

It can be noted that the specific structure of this material, which is different of the soil one, determines peak cohesion values lower then the residual ones, while the friction angle, ϕ has an inverse variation.

2.1.3 *Special tests*

2.1.3.1 Water erodability

Two tests were performed in order to assess the erodability of the dehydrated sludge:

- the TS test – erosion due to the water movement. After 15 min stirring, the sludge mass loss was of 10%, corresponding to a low to medium erodability (Table 1, Monjoie et al. 1992).

Table 1. Erodability of soils – TS test (Monjoie et al., 1992)

Erodability	% of loss
high	> 50%
medium	10 – 50 %
low	<10%

- the slaking test – the sensibility to disintegration by immersion. After 24h of immersion, 10% of the material was eroded in pieces. Taking into account the following classification, the sludge has a low erodability (Table 2).

Table 2. Erodability of soils – Slaking test (Monjoie et al., 1992)

Disintegration	Quantity % of disintegration	Aspect
high	after 1h: 100%	dispersion and mud
medium	after 1h: max. 50%	disintegration and mud
	after 24h: max. 100%	disintegration in pieces
low	after 1h: max. 10%	disintegration in pieces

So, the dehydrated sludge can be classified as having low erosion potential.

2.1.3.2 Wind erosion

In order to verify the particle transport by the wind, in the laboratory of "Wind engineering" of the Technical University of Civil Engineering Bucharest were performed tests in the limit layer aerodynamic tunnel. This tunnel allows to simulate the average speed profile.

For the dehydrated sludge in natural moisture state, as well as for the dry samples, no transport was observed for wind speeds varying from 1 m/s to 10 m/s.

This confirms the theoretical values obtained by calculation: tangential forces p_f = 0.0016 kPa (10 m/s wind speed) and p_f = 0.04 kPa (40 m/s wind speed) are much less then the cohesion (c = 17 kPa) and shows no sensibility of the dehydrated sludge at the wind erosion (Hennensal, 1993).

For the completely dry sludge, no wind transportation of particles was observed, only the mechanic impact with various objects being able to produce particle dislocations.

2.2 *Hydraulic tests*

In order to choose a drainage geocomposite to be used in the future landfill, permeability tests were performed on sludge samples having a geotextil + geonet + geotextile geocomposite at their lower part.

The geocomposite technical data are presented in Table 3.

Table 3. Technical data for the used drainage geocomposites

Geocomposite 1 – composed of a HDPE geonet and two nonoxen geotextiles on both faces

Geogrid characteristics:

Mass	0.98 kg/m^2
Thickness	5.6 mm
Density	0.95 g/cm^3
Melting flow index	≤1 g/10min
Tensile strength	5.3 N/mm
Transmissivity	1.3x10^{-3} m^2/s (69 N/mm^2 confining stress and unit hydraulic gradient)

Geocomposite 2 – composed of a HDPE geonet and PP geotextil on both sides.

Geonet caracteristics:

Mass per unit area		800 g/m^2
Thickness:	2 kPa	5.3 mm
	20 kPa	3.5 mm
Transmissvity:	2 kPa	0.52 l/m s
	20 kPa	0.44 l/m s
	200 kPa	0.32 l/m s
Compressive strength		1290 kPa

Geotextile characteristics:

needle punched continuous filament nonowen geotextile
Vertical permeability 187 l/m^2 s
Opening size O_{90} 0.10 mm
Thickness 1.4 mm

The free drainage tests (drainage of the water contained in the dehydrated sludge) showed an initial tendency to accumulate water in surface, but finally the water was removed and at the upper part the scab formed. The results are presented Table 4.

Table 4. Results of the free vertical drainage of the water contained in the dehydrated sludge

Sample	Sample surface (cm^2)	Sample height (cm)	Sludge mass w = 28% (g)	Water mass in the sample (g)	Time (min) for the drainage
1*	24	3	138.9	30.38	20
2**	24	3	150.8	32.98	25

*Sample 1: dehydrated sludge + geocomposite 1
**Sample 2: dehydrated sludge + geocomposite 2

Using the same geocomposites, were performed drainage tests with a fixed water quantity, modeling precipitations. The measured permeability coefficients were of $1.3 – 1.7 \times 10^{-4}$ cm/s. It was noted a sludge accumulation in the geocomposite surface (Table 5).

Table 5. Sludge accumulation on the geocomposites surface

Sample	Initial mass (g)	Final mass (g)	Final dry mass (g)	Retained sludge mass (g)
Geocomposite 1	4.4	11.1	5.5	1.1
Geocomposite 2	2.3	11.1	5.4	3.1

Some permeability tests were performed on the geocomposites before and after the contact with the sludge. It was noted that no clogging occured, the retained sludge being washed immediately.

2.3 *Chemical analyses*

By means of chemical analyses the residual water, the water after the treatment and the resulted sludge were characterized.

Tables 6 and 7 show the results and the maximum allowed values according to the NTPA 001/1997.

Table 6. Chemical analyses for the sludge

No.	Chemical element	Concentration in sludge (mg/dm^3)	Maximum allowed value (mg/dm^3)
1	Al	52.94	8
2	Ca	7600	300
3	Pb	22.65	0.2
4	Cd	2.84	0.1
5	Cr total	8.5	1.1
6	Fe total	14684	5
7	Ni	9.595	0.1
8	Zn	2268.5	0.5
9	Mn	85.1	1
10	Mg	950	100
11	Co	2.57	1
12	As	2.56	0.05
13	Cu	12.57	0.1
14	Sr	1.715	-

Table 7. Chemical analyses for the water after the treatment

No.	Indicator	U.M.	Value	Maximum allowed value
1	pH	-	7.89	6.5 – 8.5
2	Alkalinity	meq/l	3.6	-
3	Total hardness	german degrees	21	-
4	Temporary hardness	german degrees	10.08	-
5	Permanent hardness	german degrees	10.92	-
6	Ca	mg/l	208	300
7	Mg	mg/l	13.3	100
8	Bicarbonates	mg/l	219.6	-
9	Chlorides	mg/l	479.25	500
10	Sulfate	mg/l	156	-
11	Nitrate	mg/l	25.1	25
12	Nitrite	mg/l	0.374	1
13	Ammonia	mg/l	0.68	2
14	Organic substances COD-Mn	mg/l $KMnO_4$	6.004	40
15	Organic substances COD-Cr	mg/l O_2	9.6	70
16	Al	mg/dm^3	0	8
17	Pb	mg/dm^3	0	0.2
18	Cd	mg/dm^3	0	0.1
19	Cr total	mg/dm^3	0.013	1.1
20	Fe total	mg/dm^3	0.233	5
21	Ni	mg/dm^3	0	0.1
22	Zn	mg/dm^3	0	0.5
23	Mn	mg/dm^3	0.015	1
24	Co	mg/dm^3	0	1
25	As	mg/dm^3	0.040	0.05
26	Cu	mg/dm^3	0.010	0.1
27	Sr	mg/dm^3	0.760	-

For the sludge it can be noted the large amount of iron, calcium, zinc, magnesium, manganese, lead, copper etc.

Some chemical analyses were also performed for the effluent collected after the permeability tests with sludge and geocomposites, being noted a washing of some chemical elements (Ca, Cl etc.)

3 TECHNICAL SOLUTIONS PROPOSED FOR THE LANDFILL

Figure 1 shows a cross section of the landfill with the two compartments.

Two solutions were studied for the lining system. The first one includes:

- a separation and filtration geotextile;
- a mineral filtration layer 16/30 mm, 0.60 m thick;
- a protection geotextile;
- a HDPE geomembrane textured on both sides for the slopes and on one side for the bottom as active barrier;
- a Geosynthetic Clay Liner (geotextile + bentonite + geotextile) as passive barrier, with a maximum permeability coefficient of 10^{-10} cm/s.

The second solution was proposed after the hydraulic tests performed on drainage geocomposites and replaces the protection and filtration geotextile and the mineral drainage layer with a thin drainage geocomposite (Figure 1). It has the advantage of a lower thickness by replacing 2 geotextiles and a 0.60 m thick granular layer with only one geosynthetic material.

It was considered that the double lining system with geomembrane and Geosynthetic Clay Liner will be efficient against the chemical attack of leachate.

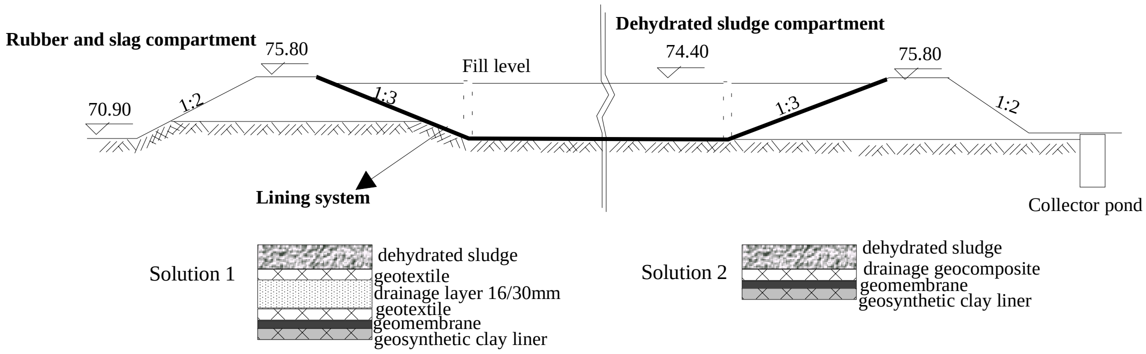

Figure 1. Cross section with the lining system

Taking into account the chemical composition of the sludge (heavy metals, Ca, Mg) it can be forecast a good behavior of the geomembrane, which is not influenced by these chemical species. In the case of a geomembrane puncture, the Geosynthetic Clay Liner will swell and its permeability will be of maximum 10^{-8} m/s, depending of its initial water content (Batali-Comeaga, 1997). However, some laboratory tests will be necessary to perform on the chosen GCL, in order to meet the required specifications. Due to the fact that the GCL is placed directly on the natural clayey soil, it is expected to have sufficient initial moisture content (by suction) to resist to the chemical attack. The main problem relative to the GCL is the relatively large amount of calcium, being known that it can replace the sodium of the bentonite, increasing so its permeability. However, even a small initial water content is enough to obtain good leachate permeability. Some of the heavy metals will be fixed into the bentonite layer.

4 CONCLUSIONS

The waste resulted from the technologic process exhibits some specific physic, chemical and mechanic properties which have been determined in the Technical University of Civil Engineering laboratories by means of traditional and special tests.

The dehydrated sludge to be stored in the future landfill is similar to a silt, but with no plasticity or swell. It has a low to medium compressibility and a shear strength characterized by a friction angle $\phi = 37°$ and a cohesion c = 17 kPa. This parameters are expressed as for soils, but in this case the cohesion is due not to the water – particle interaction, but to the chemical bonds.

The dehydrated sludge has a low sensibility to water and wind erosion.

The chemical analyses showed a large concentration of heavy metals, metals, calcium etc.

On the base of the experimental program results, it was proposed a double lining system using geosynthetics: a HDPE geomembrane combined with a Geosynthetic Clay Liner composed of two geotextiles and a bentonite layer, presenting some advantages related to the installation facility, the complementarities between the two materials, the self healing property of GCLs etc.

Some further laboratory tests are necessary in order to correctly assess the GCL behavior in contact with the real leachate.

REFERENCES

Batali – Comeaga, L. 1997. *Dispositifs d'étanchéité par Géosynthétiques Bentonitiques dans les centres de stockage de déchets.* PhD thesis, INSA Lyon, France

Henensal, P. 1993. Lutte contre l'érosion avant, pendant et après les travaux, *Etudes et recherches des Laboratoires des Ponts et Chaussées*, GT54

Monjoie, A, Rigo, J.M., Polo-Chiapolini, C. 1992. *Vademecum pour la réalisation des systèmes d'étanchéité – drainage artificiels pour les sites d'enfouissement technique en Wallonie*, Liège