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ASPECTS REGARDING SLOPE STABILITY/INSTABILITY DETERMINATION IN THE OPERATION OF URBAN WASTE COMPLIANT LANDFILL

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Abstract: The main objective in designing of compliant landfill is the total isolation from the environment, therefore reducing their polluting nature towards the environmental factors. An important aspect of the sustainability of urban waste landfills is to ensure the functionality of its components. A common problem in the operation of urban waste landfills is establishing the bearing capacity limit, local stability of the site in general and slope areas in particular. The paper aims to identify the main causes of slope instability in urban waste landfills, and the best Geocomposites and Geosynthetics materials used to increase the carrying capacity of the land. For this purpose is shown the funnel effect that occurs due to heavy rains, an effect that produces sharp erosion in recultivation layer and waterproof barriers making it impossible to work in many areas of urban waste landfills in operation around Europe.

Keywords: biodiversity, land usage, quality limitation, pedoclimatic conditions, bioproductive capacity.

1. INTRODUCTION

Landfill is critical to most waste management strategies, because it is the simplest, cheapest and most cost-effective method of disposing waste. Although in the future, waste minimization and recycling programs will reduce waste volumes, and other waste treatment options may be developed, at the end of the day landfills will still be required to accommodate residual waste [1], [2]. Due to environmental and health risks from landfills, a significant number of nations and international organizations (EU, World Bank, UN, etc.) have developed, in recent decades, specific rules for the location, design, operation and control of landfills. This legislation looks forward to minimizing the environmental impact generated by the landfills.

2. BACKGROUND

Landfills closure in our country consists in a combination of standard closing and simplified procedures [12]. This activity is done in two phases: phase I - temporary closure; phase II - the final closing, which is performed after the stabilization of the landfill body, and if the results of monitoring of surface and groundwater and landfill gas shows that closure is necessary and can be done safely. The municipal landfills are submitted to the Government Regulation no. 349/2005 and Ordinance 757/2004. The main works in landfill closure are structured in three categories:

Preparation works

Temporary closure and relocation of waste for the installation of landfill gas collection and leachate. Waste from the extremity of the landfill are restricted inward to create the perimeter to insert/seal edge layers and create space for process equipment (such as access roads, leachate treatment facilities, burning landfill gas, sewage systems, etc.); Building the intermediate sealing and surface water collection system; Internal infrastructure construction jobs require closure.

Restriction and leveling works:

Reconstruction of the waste pile slopes at a 1:3 slope and top of the pile with a slope of min. 5%.

New closure system:

Achieving final sealing layer system: ground coating thickness of 1.0 m, 0.30 m from the plant floor to the top (over soil cover); geotextile layer, a drainage layer with a thickness of 0.50 m, made of sorted gravel 16-32 mm, for collecting infiltration water; geotextile layer, compacted clay layer thickness of 0.5 m; perfect gas drainage layer made of gravel 8-32 mm diameter, perimeter channels on the upper terrace and the deposit base (lower terrace); transverse channels for the meteoric water collected in the perimeter channel on the surface of the upper and lower terraces.

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3. FACTORS THAT CAUSES THE SLOPE INSTABILITY – CASE STUDY PRESENTATION

3.1 Slope instability due to the stratification of the roof top

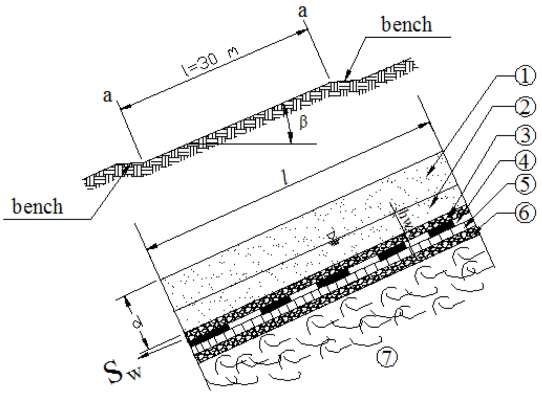

Figure 1. Layers that compose a landfill roof top

The notations used in Figure 1 are:

1. Topsoil layer / support Bioprotection (d = 1.00 m);
2. Accumulation layer of water infiltration (hw = 0.01 m);
3. Leachate collection drainage layer (Secudrän);
4. Seepage barrier sealant (Membrane);
5. Sealing barrier for biogas (Bentofix);
6. Drainage layer for capturing biogas (Secudrän);
7. Landfill body.

Given the heterogeneous layers composing a landfill (see Figure 1), it is necessary to check their stability in sloping areas (the event of slipping layers of different embodiments slope areas: contact areas between Secudrän and Geomembrane or for the roof area the Geomembrane and Bentofix respectively Secutex and Geomembrane in foundation areas [3].

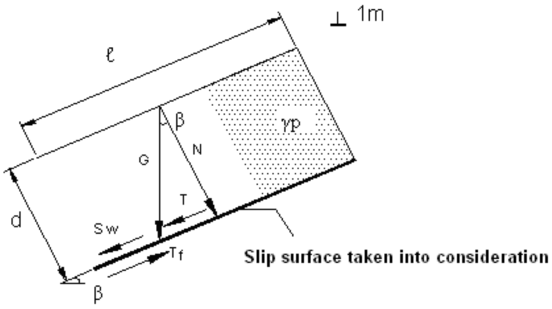

Figure 2. Forces involved in the slope areas of a compliant landfill

To check the stability of these layers is defined a safety sliding coefficient as the ratio of stability forces (friction forces that oppose to the slip) and the forces of instability (sliding forces - forces resulting from the weight of the layers that compose the roof top):

$$\eta = \frac{F_S}{F_L} = \frac{F_f}{F_g} \qquad (1)$$

The forces involved in the sliding and mechanical stability of the layers in the areas of contact between them (see Figure 2) are:

- G – the weight of the layer on top of the sliding surface

$$G = \gamma_p \cdot \ell \cdot d \cdot 1m \qquad (2)$$

with components:

$$N = G \cdot \cos\beta = \gamma_p \cdot \ell \cdot d \cdot \cos\beta \qquad (3)$$

$$T = G \cdot \sin\beta = \gamma_p \cdot \ell \cdot d \cdot \sin\beta \qquad (4)$$

$$S_W = \gamma_W \cdot h_W \cdot \ell \cdot \sin\beta \qquad (5)$$

where: – the weight of the water layer (from rainfall) stationed above the sliding surface (membrane).

(tf/m3 / KN/m3) – specific weight for the earth layer and for water infiltration layer.

– the friction force the material verified layers from sliding:

$$T_f = f \cdot N \qquad (6)$$

where: - the friction coeficient (- the friction angle);

$$T_f = \left(tg\delta'\right) \cdot \gamma_p \cdot \ell \cdot d \cdot \cos\beta \qquad (7)$$

- retention force from geogrid (usually neglected in the calculations);

$$z' = a' \cdot \ell \cdot 1m \qquad (8)$$

where: a' (KPa) – geogrid adherence;

The relation for th safety slip coefficient (1) by replacing the relations mentioned above becomes:

$$\eta = \frac{\left(tg\delta'\right) \cdot \gamma_p \cdot \ell \cdot d \cdot \cos\beta + z}{\gamma_p \cdot \ell \cdot d \cdot \sin\beta + \gamma_W \cdot h_W \cdot \ell \cdot \sin\beta} \qquad (9)$$

Note.: 1) First we check the slope stability slip without incorporating the geogrid:

$$\eta = \frac{T_f}{T + S_W} \qquad (10)$$

2) If the safety factor value is lower than the limit value (η = 1,30) it results as necessary the constructive method that involves the use of geogrid; the force required to be supported by the geogrid to prevent the layers from slipping is determined according to the relation:

$$z_{nec} = \eta \cdot \left(T + S_W\right) - T_f \qquad (11)$$

Depending on the value that will result from z_{nec} the type of geogrid will be chosen from the specifications in data sheets provided by the manufacturers;

3.2 Slope instability due to hydro transport leaching from soil particles in the vegetal topsoil

Drainage of any kind causes entrainment of fine particles of soil through the drainage plan (hydro transport) due to the power lines and hydrodynamic current. This undesirable phenomenon causes an increased porosity in the layer of earth/soil on top of the drainage work. In time compaction will occur in this layer (and in particular in the vegetal topsoil) and simultaneously the cracking of horizontal and vertical planes under the influence of changes in temperature and humidity [3].

Finally the layer in question is subject to the slipping phenomenon. This will compromise the basic functions of the vegetal topsoil.

In addition hydro transport causes the clogging of the drainage system, in other words, will reduce its capacity to capture and transport water [7].

Methods to improve this phenomenon until safe values are obtained using the granular filter material or geotextile layers.

3. DISCUSSION

Incorrect geometrical design of the slopes is the main cause for structural failures that can occur in a landfill. In order to evaluate the correct safety factor of the slope in a landfill we must know the mechanical and physical properties of the deposited wastes [10]. Most researchers agree that among these properties are the density and humidity of the deposited wastes. The density (g) depends directly on the composition, moisture and the degree of compaction and is one of the needed parameters to determine the stability of a slope [4]. Other required parameters are the effective cohesion (C'o) and the effective friction angle (F'). C'o and F’ are determinate through laboratory tests. Unfortunately due to the heterogeneous composition of the waste material (plastic, fabric, organic material, paper, metal, etc.) and various particle size (from small pieces of organic material to large cardboard or plastic film type) the results are very differ widely between different trials, even within the same landfill so various tests can provide a range of values. Also, depending on the depth where the test is carried out, the density variation is much greater than in soils. Waste lifespan also has an influence, for example fermentable organic matter is degraded forming liquids and other simpler compounds. On the other hand, extracted samples modify the properties with respect to their state at the dump, since in the extraction process; the samples suffer disintegration [9]. When samples are received in the laboratory they are compacted in the test kit for testing. Therefore, the results obtained in the test will differ from the original [5]. We can conclude that the wastes deposited in a landfill suffer continuous transformation and therefore is very difficult to fit them into a single value when it comes to establish their properties. Calculation of slope stability can also be performed using the software "Slope Stability" designed by professor Rechea from the School of Architecture of the Polytechnic University of Valencia (Spain), developed from the modified Bishop method. This academic software was developed and validated by the doctoral thesis of F. Zapata [11]. Calculations of diagrams are recently based on software Slope/W 2012R [13]. In the following set of diagrams (Figures 3, 4 and 5) are presented estimation of the mechanical properties of the wastes, taken into consideration three hypotheses for the effective cohesion: low values (C’o = 1 t/m^2), medium values (C’o = 2 t/m^2) and high values (C’o =3 t/m^2). The values of effective friction angle are F’=10^o, 15^o, 20^o and 25^o. The wastes density is γ = 0,9 t/m^3. The mechanical properties of the soil (bedrock) and the dam in the base have been: g = 2 t/m^3, C’o = 5 t/m^2 and F’ = 25^o. The seismic coefficient was considered zero by the authors of these simulation. Therefore graphics have been made for each of the calculation. For each inclination and/or height of the slope, SF can be calculated with the dam 10 m high at the base and without it. The data are plotted in Figures 3, 4 and 5.

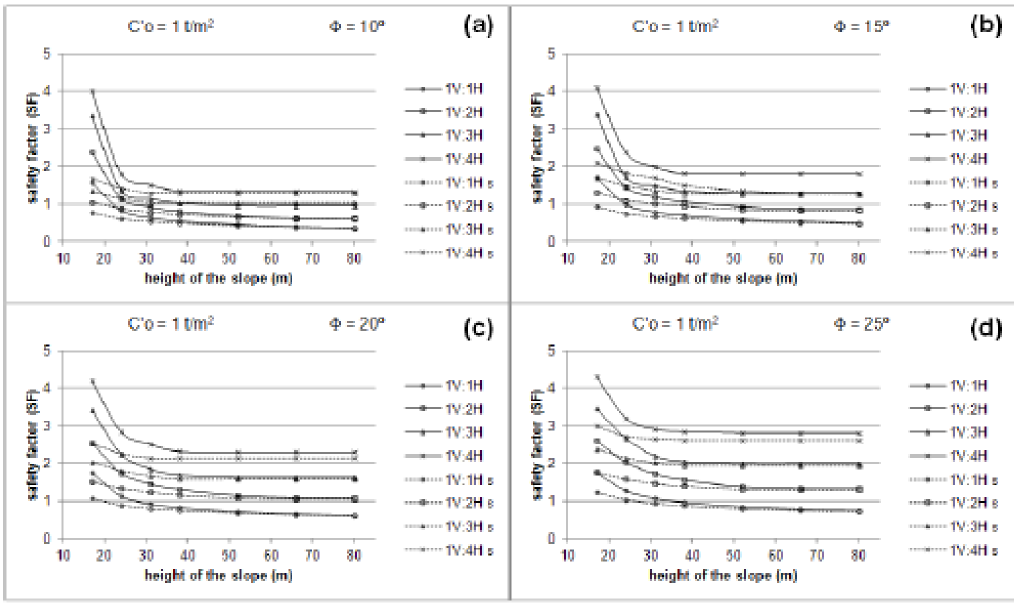

Figure 3. Relationship between the height of the slope and SF for values of effective cohesion C’o=1 t/m^2 (without dam at the bottom) [6]

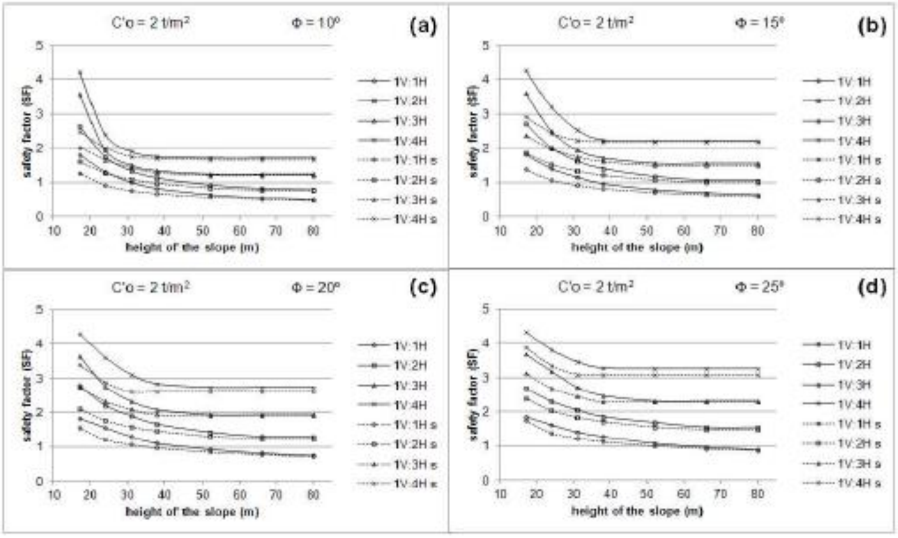

Figure 4. Relationship between the height of the slope and SF for values of effective cohesion C'o=2 t/m^2, without dam at the bottom [6]

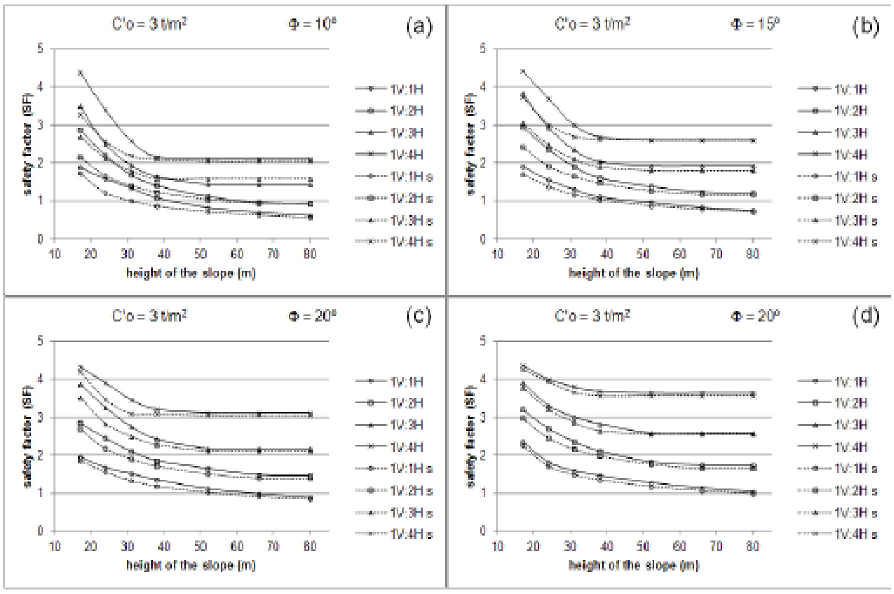

Figure 5. Relationship between the height of the slope and SF for values of effective cohesion C'o=1 t/m^2, without dam at the bottom [6]

In Figures 3, 4 and 5, the interdependence and slope height is shown. Therefore, if the mechanical properties of the waste and the geometry of the slope (width of the berms, inclination, etc.) are known the height of a landfill slope can be calculated [6].

Slope failure may occur without warning, but most times cracks are observed in landfill cover soils or materials prior to failure. Generally, cracks in landfill cover soils result from settlement and are associated with waste decomposition and consolidation. Tension cracks can occur when waste moves due to instability Astute field personnel must distinguish between settlement cracks, which do not threaten stability, and tension cracks, which are indicative of slope instability. Insufficient design and construction or improper operation may result in geotechnical problems regarding landfill operation [8].

5. CONCLUSIONS

Several stability analysis methods can help to determine whether a proposed landfill design will be stable and exhibit an adequate safety factor. The safety factor can be calculated by hand.

But owners generally input data that describes the landfill's cross-section, the unit weight of the landfill materials, and the shear and interface strength of the materials in and under the landfill into a computer program to locate the critical failure mode.

The failure mode is the option that exhibits the lowest safety factor and usually involves the material or interface with the lowest shear resistance. If the safety factor is less than desired (the regulated value usually is 1.5), then the facility design can be modified and a new safety factor can be computed. This is repeated until an appropriate design and safety factor is achieved.

Computer analysis can be conducted in two or three dimensions. A two -dimensional model looks at a vertical cross-section. To fully understand the landfill design, it is necessary to locate the critical cross-section, which is the cross-section that exhibits the lowest safety factor. Three-dimensional models can evaluate complex landfill geometries, shear strength conditions (e.g., part of the landfill overlying geosynthetics and part not) and leachate conditions. Landfill operators should follow two basic rules: 'protect holding forces - reduce driving forces'. Several suggested operating measures are:

- good compaction to reach high density, small settlements, and less water percolation
- homogeneous permeability and proper drainage system to prevent water barriers and improper water balance
- controlling the portion of reinforcement particles by means of tracing changes in waste composition and condition
- if necessary, measures to improve certain waste strength properties.

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