7 TYPICAL DESIGN APPROACH WITH GEOSYNTHETICS IN CAPPING

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ABSTRACT

There are various problems in civil works caused by the presence and movement of water underground. Associated problems such as seepage and piping beneath a structure can lead to unwanted structural damage or failure. To avoid these, it is important to control the movement of water by using efficient and reliable drainage systems. Traditionally, granular drains with a geotextile are used for these systems. These traditional drainage systems can be difficult to install, particularly on slopes, and depending on the availability of the material, they can lead to high costs. The use of geocomposite drains to substitute the traditional drainage method is not a new concept and can often be more advantageous. The installation of these products can be easier and faster, making it more economical. With the correct product knowledge, a more accurate and reliable design can be achieved, especially with relation to the long-term performance, whereas granular drains characteristics can change unpredictably over time, leading to underperformance and subsequent consequences. When using different geosynthetics, extensive knowledge on a product's properties is required to understand its behaviour and performance to conceive an appropriate design. It is shown two case histories, one of an effective geosynthetic solution for upgrading an existing capping system and a second of a failed slope to demonstrate the importance of complying with soil veneer design when using geosynthetics.

1 INTRODUCTION

The proper disposal of waste materials in suitable areas to ensure the protection of the environment from the harm of waste material is an important requirement for an advanced society. This results in the demand for greater landfill capacity, requiring proper management, planning and engineering to uphold the surrounding environmental conditions, keeping the waste secluded for a certain design life. Once a landfill reaches its full capacity dictated by the license given to the site, it can no longer hold waste and must be closed using a capping system that must shield the waste from harming the surrounding environment, reducing rainwater infiltration and the associated generation of leachate to a minimum level.

The term "capping" means a complex design system (which is able to satisfy a set of requirements) aimed at achieving landscape, health and environmental protection minimum requirements (Scotto & Napoleoni, 2007).

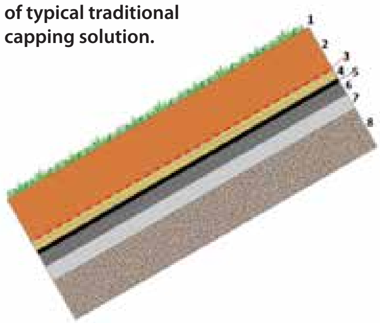

FIGURE 1. Example of typical traditional capping solution.

1.1 Traditional Capping Solutions

A traditional cover capping system requires high volumes of natural resources, requires labour intensive installation and is susceptible to erosion, making it a costly solution. For covering a landfill, several types of capping systems can be used. Some can be used for hazardous landfills, and some for non-hazardous landfills. Depending on the landfill classification, different capping solutions may be used. Figure 1 illustrates an example of a typical capping layer using a traditional solution with mostly natural materials.

A capping system can consist of an intermediate cover layer (7) above the waste material (8) followed by a grading layer (6). For an impermeable barrier layer (5), commonly, compacted clay is used as cap; however, there is a chance of cracking if the clay dries out. Therefore, a Geomembrane comprising of LLDPE or PVC (which is able to sustain higher values of deformation, due to the consolidation of the waste body) is often used in place of the clay. The aim of the drainage layer (4) is to intercept, collect and dispose of the infiltrating rainwater, and to avoid waterlogging of the cover. The correct operation of this system is also essential for the growth of vegetation (1), as the moisture content in the soil (2) must be maintained at a level that sustains growth. Traditionally, the drainage layer may consist of a selected gravel with a thickness of up to 0,5 m (according to European standards) and is accompanied generally by a geotextile (3) to perform the function of separation and filtration, allowing water to pass through to the drainage layer while retaining the fines form the soil layer above. The outer layer (2) consists of top soil and the thickness must be sufficient to enable the growth and development of an adequate vegetative cover. As per European Standards (Figure 2), the thickness used until now on flat surfaces varied between 0,5 and 1,0 m and hardly ever exceeded 0,5 m on slopes.

Although it is not relevant to this paper, and for this reason not shown in Figure 1, it should be noted that the grading layer can be covered by a biogas drainage layer and a waterproofing layer where biogas needs to be collected for recovery or venting. These layers are subject to the same design principles as are described in this paper, for the outer layers (layers 1 to 4 in Figure 1).

1.2 Geosynthetics in Landfill Capping

The use of geosynthetics in a capping system can significantly reduce costs. Figure 3 illustrates the use of geosynthetics in the outer layer.

Drainage geosynthetics such as geocomposite drains illustrated in layer 2 in Figure 3 can be used as an alternative to a typical granular drainage layer. Geogrids or reinforced turf mats can also be introduced to increase the stability of the soil cover (Layer 1) and erosion control blankets/mattresses can be used to not only protect the soil surface from erosion, but also to assist in the sustainable growth of vegetation (Layer 3).

When using different geosynthetics and design approaches extensive knowledge on a product's characteristics is required to understand its behaviour and performance in order to develop an appropriate design.

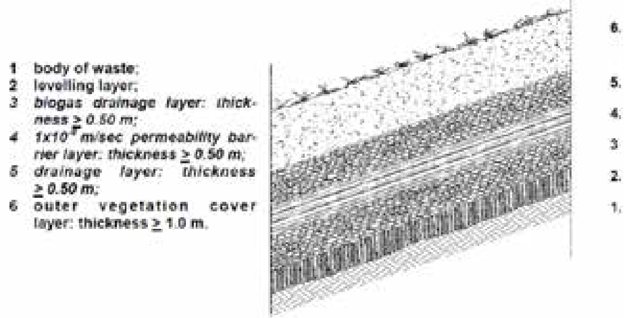

FIGURE 2. Capping example as per EN Standardization (Scotto & Napoleoni, 2007).

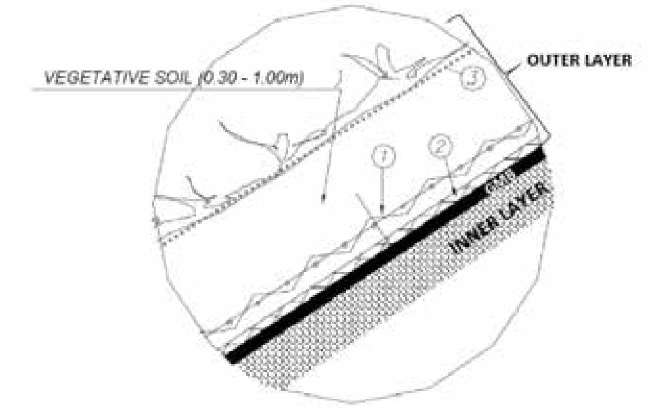

FIGURE 3. Inner and Outer layer of capping (Scotto & Napoleoni, 2007).

2 DESIGN APPROACH FOR MULTI-LAYERED CAPPING

The properties and the behaviour of the waste influence the performance of the cap, and must considered in the design and in construction (Shukla, 2012). One of the typical problems which the designer must deal with when using multi layered materials (soil or geosynthetic) is the stability of the layer above on the layer below. An adequate factor of safety against sliding is required. The analysis procedure is called veneer design and is controlled by the interface friction angle between the materials which can be soil-soil, geosyntehtics-geosynthetics or soil-geosynthetics. The interface friction angle is characterized by a dry value and wet value. Wet friction angles can reach values below 10° for soil-geomembrane (e.g. in a cover where infiltrating rainwater is not suitably and effectively drained or in a base barrier where accumulation of leachate brings about saturation). The drainage design is therefore important in ensuring stability.

2.1 Soil Veneer Design

In a soil slope, a stability calculation is required to assess the factor of safety for sliding on the barrier layer. In a landfill, there are four situations scenarios that should be considered:

- Landfill liners with leachate collection sand or gravel above them.
- Surface impoundment liners where the cover soil is placed over the geomembrane to shield it from ultraviolet light, heat degradation, and equipment damage.
- Landfill covers that have topsoil and protection soil placed over the geomembrane.
- General slopes and embankments containing geotextiles or erosion control materials being covered with a layer of soil.

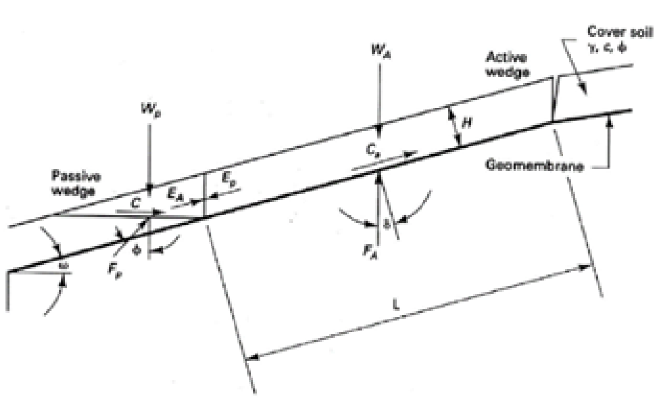

FIGURE 4. Diagram of forces in soil veneer (Koerner, 2012).

In all four of the above-mentioned scenarios the soil layer is relatively thin (0.3 to 1.0 m), hence the sliding stability of such a veneer of cover soil is the issue (Koerner, 2012).

Each of the layer interfaces must be in equilibrium with an adequate factor of safety between the forces destabilizing the cover layer and the stabilizing forces. These forces are shown in by a diagram in Figure 4.

A limit equilibrium equation is taken from this diagram which enables the use of geosynthetic reinforcement to be taken into account inside the soil layer with a thickness H.

To determine whether reinforcement with geosynthetic materials is required, a quick evaluation can performed by checking the compliance of the equilibrium condition between the tangent of the friction angle for the soil/ geosynthetic interface (δ) and the slope angle (ω), as per Equation 1:

$$\frac{\tan\delta}{\tan\omega} \quad (1)$$

When the value of Equation 1 is higher than 1.3 (proposed value), mechanical reinforcement of the soil cover is not necessary. However, lower than 1.3, mechanical reinforcement is necessary.

If the equilibrium condition is not complied with, it is possible to calculate the working strength value for the reinforcement by using the following Equation 2 (Scotto & Napoleoni, 2007).

$$\frac{W \cdot \cos\omega \cdot \tan\delta + C_a \cdot L + R_{reinforcement}}{W \cdot \sin\omega} = FS > 1.3 \quad \text{(proposed value) (2)}$$

Where:

W = weight of the mass placed above the geosynthetic material and/or of the waterproof package = γ H;

ω = slope angle

δ = soil/geosynthetic interface friction angle (experimental value)

L = Length of slope

C_a = soil/geosynthetic material adhesion (experimental value usually assumed to be zero)

$R_{reinforcement}$ = long-term tensile strength of the reinforcement member

The working strength defines the long-term strength of a product. An evaluation is done to determine the effects of viscous deformation phenomena such as creep and all reduction factors that take into consideration mechanical damage and chemical-environmental damage. These findings are used to determine the long term strength a geosynthetic is usually characterized by.

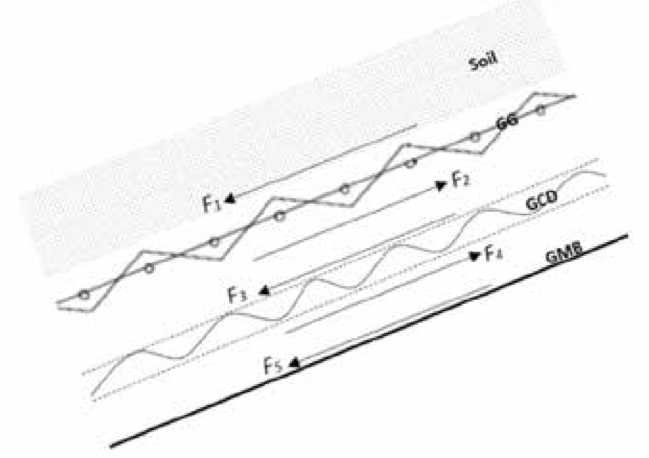

FIGURE 5. Exploded view of liner system.

Figure 5 illustrates a multi layered capping system (on an infinite slope) where a mechanical tensile check should be carried out for the individual layers of the materials which have been selected and used. This aims to verify that the stresses induced by the overloads and transmitted between the various layers in accordance with the interface friction angle between the various layers of geosynthetics and the angle of the slope are compatible with the mechanical strength of the various geosynthetic materials.

As different geosynthetic materials possess different interface friction angles, the upper and lower faces of a layer are subjected to different forces. This can cause an unbalance between the two tangential stress components applied to the layer, and the one that prevails is that applied to the upper face, the upper face will be subject to tensile forces. It will therefore be necessary to check that this is compatible with the mechanical strength of the component.

It is considered good practice not to apply tensile forces to the geomembrane and to ensure that the balance of the stresses on the two interfaces is always neutral (F4 = F5) or the geosynthetic is in compression (F4 > F5). In the case this is not possible, the component that induces compressive stresses and not tensile stresses in the membrane should prevail. Some designers suggest that stresses that can lead to a deformation of 2,5-4%, should not be applied to the membrane, which is equivalent to applying a safety factor of approximately 4 with respect to the yield state of a HDPE membrane (Scotto & Napoleoni, 2007).

It is important to take into account the pore pressures and presence of a drainage geocomposite (which is always recommended) and of a highly permeable layer which is able to effectively drain away rain water.

2.2 Drainage Design

In order to avoid the build-up of water on/in the cap, a drainage layer is usually installed in the system above the geomembrane. In German landfills, the minimum gradient of the cap drainage layer is 5% and in long slopes, the maximum inclination should not be steeper than 1(Vertical) in 3(Horizontal). The maximum slope is limited for practical reasons with respect to landscaping and maintenance work (GGS, 1991).

The design of drainage for a landfill cap begins with the calculation of input flow rate. Although this is project specific, it is possible to provide indications only for the most common and simple cases. The input flow from rainfall onto a sloping surface is of interest in many situations such as landfill capping. Figure 6 illustrates the scheme for the calculation of the input flow rate in the case of rainfall on a sloping surface based of Darcy's Law.

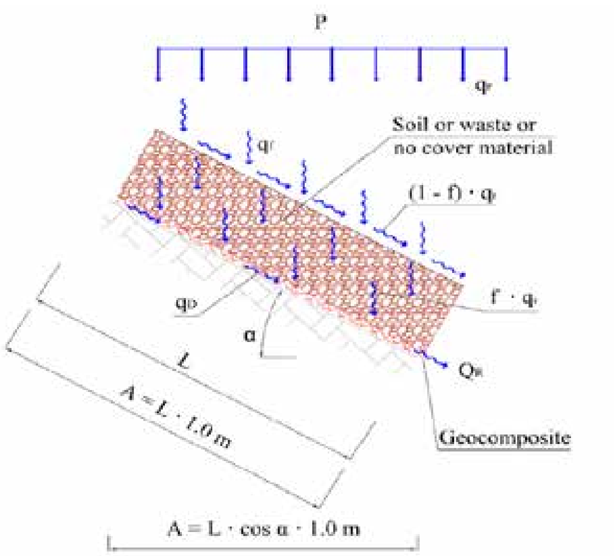

FIGURE 6. Scheme for the calculation of the input flow rate.

For all applications, the available flow rate of the geocomposites shall be obtained by applying a set of Reduction Factors (Cancelli & Rimoldi, 1989) which take into account all the phenomena that may decrease the flow rate over the entire design life compared to the short term flow rate measured in the tests according to EN ISO 12958:2010 or ASTM D4716 - 08(2013) standard:

$$Q_a = \frac{Q_L \cdot F_{lr}}{RF_{in} \cdot RF_{cr} \cdot RF_{cc} \cdot RF_{bc}} \qquad (3)$$

Where:

Q_a = available long term flow rate for the geocomposite;

Q_L = short term flow rate obtained from laboratory tests;

RF_{in} = Reduction Factor for the intrusion of filter geotextiles into the draining core;

RF_{cr} = Reduction Factor for the compressive creep of the geocomposite;

RF_{cc} = Reduction Factor for chemical clogging of the draining core

RF_{bc} = Reduction Factor for biological clogging of the draining core

F_{lr} = Empirical factor to be applied when the test results for QL are available for contact conditions different from the project conditions

The Reduction Factors shall be set considering the specific conditions of each project, taking into consideration the experience and/or research on similar conditions of use.

Once the design input flow Q_D has been calculated, the available input flow Q_a shall be calculated for one or more geocomposites. The final Factor of Safety FS_G afforded by the design with each geocomposite is given by:

$$FS_G = Q_a / Q_D \qquad (4)$$

Only those geocomposites for which $FS_G \geq 1$ are suitable for the project. The final selection of the geocomposite shall be performed among the geocomposites for which:

$$FS_G \geq 1.00 \qquad (5)$$

taking into consideration also costs and availability.

2.3 Anchoring

The "fixing" of the geomembranes and other layers at the top of a slope is a fundamental problem and is a requirement to all geosynthetic materials to which tensile forces are applied. The most commonly used form of fixing is by excavating a trench at the top of each slope inside which the geosynthetic material (this term is also used to indicate a geomembrane and any other type of related product) will be fixed. The trench is filled with adequately compacted soil or aggregate. Some designers propose a concrete crown to the trench (sometimes lightly reinforced) whilst others prefer to use loose material considering that it is preferable for the anchored geosynthetic material to slide out of the trench rather than break. If a double membrane layer is used, or there is a large number

FIGURE 7. Single-anchor trench (left) and separate anchor trenches (right).

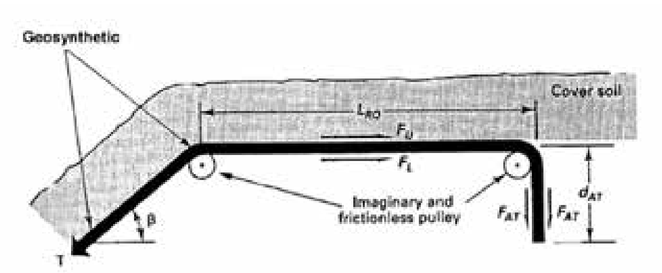

FIGURE 8. Anchor trench design layout.

of geosynthetics to fix at the top or the level of stresses applied to the various materials is high, use of a double anchor trench is recommended as shown in the following Figure 7:

The design of the trench is normally carried out with a method which should safeguard the designer both in terms of pull-out phenomena and actual breakage. Figure 8 illustrates the design layout in which it is assumed the presence of frictionless pulleys which transmit the entire tensile force acting on the geosynthetic material, enabling the equilibrium condition to be satisfied. More detailed information regarding anchor trench design can be found in literature (Scotto & Napoleoni, 2007 and Qian et al. 2002).

3. CASE STUDY

3.1 Tubatse Ferrochrome Mine, South Africa (Dode & Legg, 2016)

In Dode and Legg, 2016, the solution to upgrading the capping system of a ferrochrome smelter to comply with the local legislation is discussed. The facility was originally capped in 1999 with concrete filled geocells. The cells began to crack on the outer slopes due to the settlement of the waste body as shown in Figure 9.

To overcome the stability challenge associated with a steep side slope 1V:1.5H, an engineering solution using geosynthetics was applied to effectively upgrade the cap. The capping system design is presented in Figure 10 and Figure 11 and consists of the following layers (from bottom up):

a) Existing concrete surface to be repaired locally to remove any sharp protrusions and to fill any voids;
b) Non-woven, needle punched geotextile and seams overlapped and heat-bonded, placed onto the existing concrete surface;
c) 1.5 mm thick HDPE geomembrane liner (single textured, facing down);
d) Geocomposite drainage layer;

FIGURE 9. Large cracks in the existing cap side slopes.

FIGURE 10. Capping system over steep side slopes (Dode & Legg, 2016).

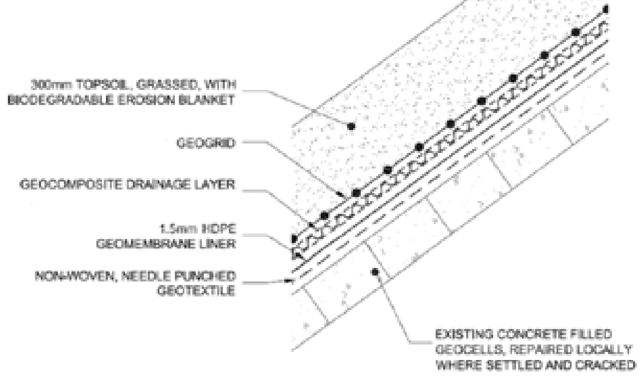

FIGURE 11. Installation of layers.

e) Geogrid reinforced geomat; and
f) 300 mm thick topsoil with grass and biodegradable erosion blanket.

3.2 Rigoloccio Mine, Italy (Favalli et al. 2002)

The first capping of a mining landfill (tailings) took place in the Rigoloccio mine, located in Gavorrano (GR) in Tuscany Italy. Detailed information regarding this project can be found in Favalli et al. 2002. The original solution for the sloped areas consisted of 0,5 m of vegetated soil, a drainage geocomposite (two geotextiles and a geonet. The barrier layer consisted of a textured HDPE membrane (2 mm thick), 0,4 m of clay over the waste, However, due to soil veneer problems during construction, the original design was modified to include an erosion control blanket and a reinforced turf mat over the geocomposite drain. Further, the soil

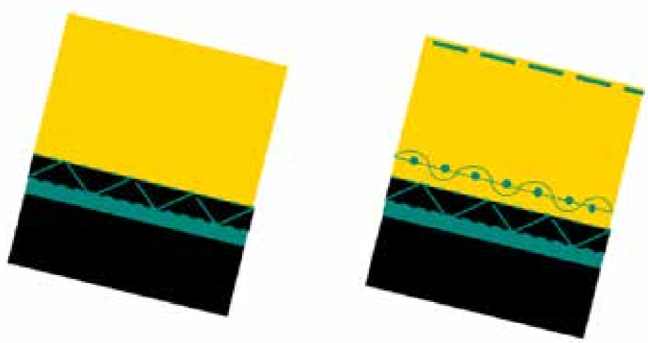

FIGURE 12. Initial design (left), modified design (right).

FIGURE 13. Slope with failure.

thickness was reduced to 0,3 m (Figure 12).

Based on the modified design, the Factor of Safety calculated for the reinforced solution was 1.77. Shortly after completion of construction, during a period of heavy rainfall, 500 m^2 of an 18 000 m^2 job had failed (Figure 13).

A site investigation was conducted and the analysis found that:

- The layer of soil was 30-40% thicker than the one designed.
- The friction angle considered had reduced significantly during the heavy rainfall and presumably the soil weight increased due to saturation.
- Failure of the reinforced section occurred predominantly at the end of the slope confirming that collapse was due to a lack of mechanical strength and, in few other sections, at different points along the slope.
- It was difficult to understand how failures occurred at other points in the middle of the mat (probably due to poor connection).

Considering the parameters obtained from the analysis, a design analysis was done in which under the field conditions, the factor of safety was found to have been reduced to 0,72, hence the result of a failure. From this experience, it can be learned:

- As the failure occurred in the reinforced mat, the textured membrane in this case did not influence the reinforcement and therefore irrelevant in the stabilization of the soil; a smooth membrane could have been used instead, reducing the costs;
- The interaction factors between the different geosynthetics are a key point; these values can varied between layers depending on the different situations and must be considered;
- Thickness and shear strength of the soil placed on the reinforced mat are relevant issues:
- The thickness (especially when small) is difficult to manage and it is likely that thicker layers will be placed in practice and thereby overload the interface with the geosynthetic;
- The unit weight (density) and also the shear strength of the soil are not homogenous and are often different from those assumed. Changing the soil unit weight and/or shear strength can also increase the loads and/or decrease the shear strength.

4. CONCLUSIONS

A brief introduction to the design of landfill capping solutions has been given. Although there are different standards around the world, these are merely a guideline to minimum requirements for the design of a capping system. Ultimately the designer should choose the most viable and economical solution without reducing the factor of safety. In general, the use of geosynthetics can reduce the total cost of capping.

Consistent design methodology is found throughout literature. However, it is important to highlight that the long-term properties of a product should be used in the design. Particularly the effects of creep which ultimately affect the long-term performance of a product must be considered.

The case studies show the importance of following the design specifications. It can be concluded from these studies that:

- The design of an erosion protection system is a real structural project and the input data must be consistent with the real situation;
- The use of a textured membrane can in some cases be insufficient and ineffective;
- The reinforcement strength must be appropriate for short term as well as long term conditions in any operating situation (dry/wet);
- Soil properties and the variations such as apply in the field are important;
- Installation should follow the design instructions strictly (e.g. Layer thickness must neither ne increased or decreased).

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