Design and set up of geosynthetic reinforcement in the case of landfill piggyback expansion

A. Abdelouhab*
Texinov, France (aabdelouhab@texinov.fr)

L. Briançon
LGCIE, Insa de Lyon, France (laurent.briancon@insa-lyon.fr)

D. Lesueur
Texinov, France

F. Cartaud
Egis, France

ABSTRACT: The aim of this paper is to present the installation procedure and design method used in the case of a real vertical extension project on an old landfill, an operation also known as “piggyback expansion”. First, the installation steps are presented for a project in Champigny-sur-Yonne (France). Then, the assumptions and design method which allowed to estimate the tensile strength of the geosynthetic reinforcement required for the project are exposed. The method used in this project is the standard French method (RAFAEL) for the design of geosynthetics in the case of soil subsidence and sinkholes. Latest improvements suggested in the literature for this method are also exposed in this paper.

Keywords: geosynthetic reinforcement, old landfill extension, differential settlement.

1 INTRODUCTION

The extension of an old landfill has been accelerating in recent years due to economic and environmental factors. In fact, current environmental constraints make it difficult if not impossible to open new landfills. So, new waste is often stored fully or partially on old waste. However, once the landfill is reaching full storage capacity, adding new volumes of waste will usually not comply with design specifications and would therefore require to reevaluate the waterproofing system. In the case of a vertical extension, where new waste would be placed on top of existing old waste, the key issue is to ensure the integrity of the new waterproofing system on top of the old waste. In geotechnical terms, the objective is therefore to prevent potential differential settlements in the old waste. One efficient way to mitigate this risk is to install a geosynthetic reinforcement on top of the old waste in order to retain the loads made by the new waste and therefore limit differential settlements.

Currently, and despite some successful projects, no systematic design method is available in order to accurately calculate the tensile strength of the geosynthetic required to retain the tensile loads made by the new waste.

In this context, this paper presents a recent successful example of vertical extension on an old landfill in Champigny-sur-Yonne (France). In a step by step approach, it describes the configuration of the project, the installation procedure and finally the design parameters and method used to estimate the required tensile strength of the geosynthetic. The RAFAEL calculation method (from the French Renforcement des Assises Ferroviaire et Autoroutière contre les Effondrements Localisés or reinforcement of road and railway foundations against localized sinkholes) was used in this project and its latest improvement were taken into account (Briançon and Villard 2008, Huckert et al. 2016). This reference method used for the design of geosynthetics to avoid soil subsidence allows calculating safely the geosynthetic strength but needs to be optimized and adaptated when dealing with waste material. The aim of this article is then to communicate the parameters and calculation methods used in this field. The confrontation and multiplication of perennial project examples will improve the construction and design methods.

2 PROJECT DESCRIPTION

2.1 *Project aim*

The project concerns the vertical extension of an old landfill, also known as “piggyback landfill”, by superimposition of a new waste storage cell on top of an existing one. The affected area is about 12 000 square meters. The height of the new cell is about 22 meters. This could lead to the settlement of the old waste and could in turn damage the waterproofing system (geomembrane and drainage system) at the bottom of the new waste. To avoid this phenomenon, it was decided to install a geotextile reinforcement to retain the loads by "membrane effect" and to limit the deformation at a maximum of 3%.

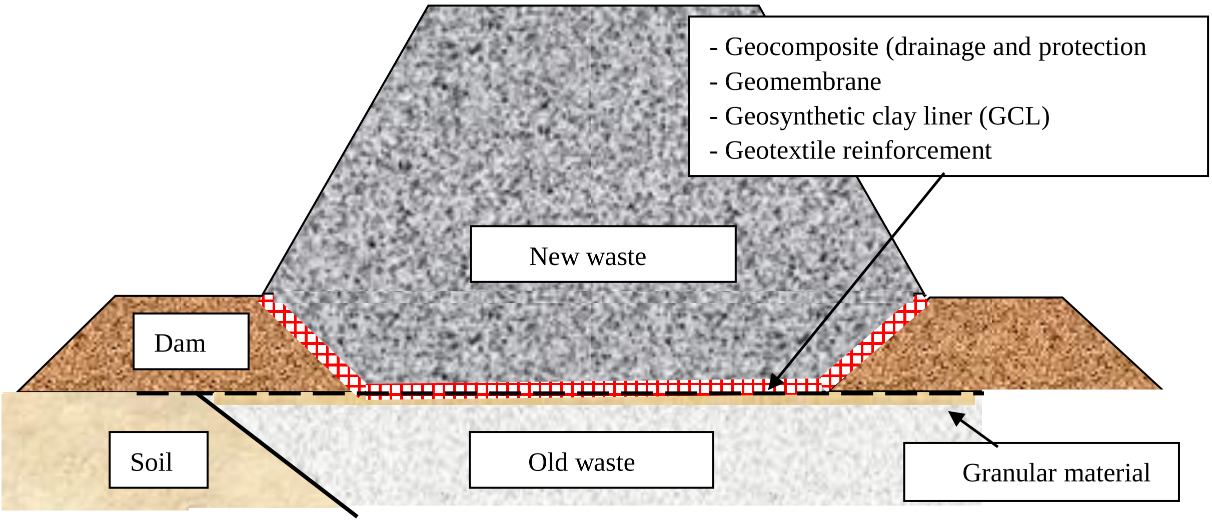

Figure 1. Cross section of landfill extension

2.2 *Site information*

The landfill of Champigny-sur-Yonne is situated approximately 100 km south east of Paris in France. The site is operated since 1981 for the storage of waste coming mostly from the Northern part of the department of Yonne. The waste treatment activities are permitted since 1981 and was renewed in 2004 for the benefit of the COVED company (Saur group). The extension project allows for the storage of 1.1 million cubic meters of non-hazardous waste separated in four cells named A, B, C and D. The first part of the works concerned the C cell with storage capacity of about 13 000 square meters.

2.3 *Waterproofing system and reinforcement*

2.3.1. *Waterproofing system*

The waterproofing of the C cell was made by a combination of geosynthetics whose placement was performed as follows. First, the top 50-cm of soil were removed after dismantling the degassing network which set up on the old waste cells. Once the upper layer of the old waste was reached, a few centimeters of granular material was spread in order to level the old landfill surface. On this granular material layer, a geotextile reinforcement was placed, a geosynthetic clay liner (GCL) was then installed and topped by a smooth HDPE geomembrane (2 mm). Above this geomembrane, a geocomposite for drainage and protection was placed in partial substitution of a granular drain.

2.3.2. *Reinforcement*

The new C cell created as part of the extension is superimposed in large part of its surface on four older cells. Thus, significant settlement of the old waste under the effect of the loads brought by the new waste is expected. The use of a geosynthetic clay liner and HDPE geomembrane at the bottom and on the sides of the old landfill, requires to limit the deformation. In fact, it is necessary to avoid damage of this active waterproofing system by the expected tensile forces created by the old waste settlement.
So, in order to control the deformation, a geosynthetic reinforcement is used to retain loads by "membrane effect" (Figure 2). This method has proven effective in several similar projects.

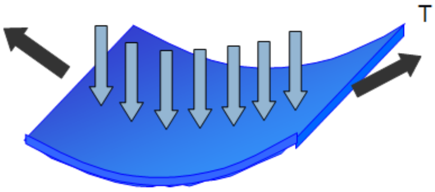

Figure 2: Illustration of membrane effect

The geotextile used in this case is made by polymer which resist to mechanical and chemical conditions of non-hazardous waste.
The geotextile is placed at the bottom of new waste and anchored at the base of the dike. After installation of the geotextile reinforcement, the waterproofing system is set up covering the bottom of the new waste and the dike slope. It is anchored on the crest of the dike at the end of the works (Figures 1 and 3).

Figure 3. Installation of the geotextile reinforcement (Geoter® FPVA) and laying down of waste

3 ASSUMPTIONS AND CALCULATION PARAMETERS

3.1 *Calculation method*

Differential settlement or excessive collapse of old waste can be compared to soil subsidence or sinkhole collapse, situations where geotextile reinforcement would commonly be used to secure the collapsing zone. The RAFAEL calculation method is used to estimate the tensile strength of the required geotextile. This design method is based on the Terzaghi theory to calculate the vertical stress on the geosynthetic at the collapsing zone and was validated by experimental tests. The deformation and tensile force in the reinforcement are obtained by membrane calculation where, by hypothesis, the anchorage part of the geosynthetic does not move and remains fixed at the sinkhole edge. This method has been validated and has been continuously improved and optimized in several research works (Briancon and Villard 2008, Huckert et al 2013, Villard et al. 2016).

3.2 Calculation parameters and structure dimensions

Basically, the RAFAEL method is used in the case of a granular backfill, characterized among other things by an expansion coefficient C_e, defined as the ratio of the soil volume before and after expansion (Figure 4, Huckert et al. 2014, Projet GeoInov, Méthode Rafael appliquée par Briançon et Villard, 2006). In the case of this project the expansion coefficient of waste materials may be taken equal to 1. This choice has no impact on the strength calculation because the expansion coefficient essentially governs the difference between surface (s) and geotextile (f) maximum deflections.

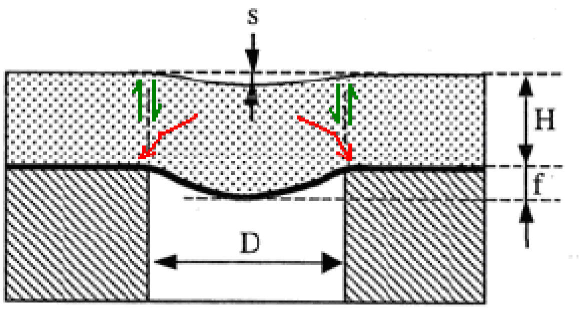

Figure 4. Mechanisms and operating principle of geosynthetic reinforcement in case of soil subsidence

The diameter of the subsidence zone taken into account in the calculation is equal to 2 m. Indeed, in the case of this project, it is believed that differential settlement occurs between two rigid points with a maximum of 2 m space. This diameter is defined according to the waste type that could settle during compaction or due to long-term degradation and consolidation.
The height H of the new waste was 22 m. So, the criteria H > 3 D was fulfilled (ie 22 > 6), allowing to make the calculation with a maximum height of 3 D = 6 m. Indeed, beyond a ratio of H/D = 3, an arching effect is created and allows for the stabilization of overlying soil volume, as confirmed in former studies with soils (Lawson and Yee, 2011, Delmas et al 2015). Note that specific studies would be needed in order to confirm that the same arching effect can indeed be found with waste.
The geotechnical parameters used for the waste were: volumic weight = 9 kN / m3, friction angle = 18° and Cohesion = 0 kPa. The Cohesion was in fact close to 22 kPa, and the choice to assign a value of 0 allowed to take into account the risk of long-term loss of cohesion.
The important design parameter in this project is the geosynthetic deflection which must not exceed 3%. This value corresponds to the allowable deformation of the geomembrane at serviceability limit state (SLS), given that the deformation at break of an HDPE geomembrane

(2.0 mm thickness) is below 6%.
The geosynthetic reinforcement was designed for a durability of 120 years. Consequently, all the durability factors were taken into account (long-term creep, installation damage, chemical durability and the safety factor on the tensile strength of the geosynthetic according to the guide ISO TR 20432).
Partial safety coefficients were applied according to Eurocode 7 - Geotechnical design.

3.3 *Calculation of required tensile strength*

As explained before, the SLS allowable strain of the geosynthetic was ε_{max} = 3%. From this deformation and after determining the vertical stress applied on the geosynthetic (taking into account the partial factors for materials and overloads), the required tensile strength Rt;d (long-term design strength) at maximum deformation ε_{max} is calculated from the RAFAEL method as:

$$R_{t;d} = \frac{\sigma_v D}{2}\sqrt{1+\frac{1}{6\varepsilon_{\max}}} \quad (1)$$

$R_{t;d}$ is then used to determine the ultimate tensile strength of required geosynthetic (short-term tensile strength Rt), applying the reduction factors following ISO/TR 20432 as:

$$R_t = R_{t;d} * RF_{\text{creep}} * RF_{\text{damage}} * RF_{\text{chimical}} * \gamma_{\text{m;t}} \quad (2)$$

The value of tensile strength required at short term Rt, allow to select the geosynthetic whose characteristic strength Rt;k is greater than or equal to Rt.

$$R_{t;k} \geq R_t \quad (3)$$

This calculation is checked at SLS and Ultimate Limit State (ULS). The SLS calculation consists in determining the tensile strength R_t at the serviceability strain (ε_{max} = 3%). The ULS calculation consists in determining the tensile strength R_t at break, which corresponds to geomembrane break in this project. The highest value of R_t is taken into account to determine $R_{t;k}$.

3.4 *Reduction Factors*

RFcreep
The creep Reduction Factor allows to take into account the creep influence on the tensile strength of geosynthetic reinforcements and to limit the deformation during the lifetime of the structure. For the ULS calculation, a creep factor corresponding to the physical break of the product should be taken into account. In the case of SLS calculation, the creep factor corresponds to the maximum creep elongation, between the end of construction and the service life. In the second case, we refer to the isochronous curves. The two criteria are usually checked for this type of project.

RF installation damage
This reduction factor corresponds to the geosynthetics damage during installation and compaction of backfill. It depends on several parameters related to both the type of geosynthetic (polymer type, fabrication, surface density ...) and the site conditions (fill material, implementation conditions, thickness of the compacted layer ...).

RFchemical
The reduction factor related to aging (hydrolysis, oxidation) of geosynthetics reinforcement also depends on the product type (PET, PVA, PP, PE, Aramid ...) and environment conditions of the product (pH…).

γm;t :
This coefficient is a safety partial factor applied for the geosynthetic tensile strength. In the French standard (NF G 38064) $\gamma_{m;t}$ = 1.25. Other values are applied in other countries and standards.

3.5 *Calculation of anchorage and overlapping of the geotextile*

3.5.1. *Longitudinal anchorage and overlapping*

It is necessary to determine the longitudinal overlapping between geotextiles and the anchorage at the geotextile edges. For the anchorage, we take into account the soil/geosynthetic friction and for the overlapping we consider the soil/geosynthetic friction on one side and geosynthetic/geosynthetic friction on the other side.
The principle of calculation is the same for both cases:

$$L_L = \frac{T_{max} * \gamma_{mf}}{\left[(\gamma * H + Q) * (C_{i\Phi 1} * \tan\Phi)\right] + \left[(\gamma * H + Q) * (C_{i\Phi 2} * \tan\Phi)\right]} \quad (4)$$

T_{max}: tensile force on the anchorage $R_{t;d}$
γ_{mf}: partial factor applied on the interface shear strength
Q: permanent overload
ϕ : internal friction angle of the confinement materials
H : materials height above the geosynthetic
γ: volumic weight of confinement material
$C_{i\varphi j}$: interaction coefficient at the soil/geosynthetic interface or geosynthetic/geosynthetic interface (it depends on the type of geosynthetic and confinement material).

3.5.2. *Overlapping in cross direction*

The overlapping in the cross direction of the reinforcement is necessary even for an unidirectional reinforcement to ensure sheets continuity.
The overlapping width in cross direction in the case of an unidirectional reinforcement, should be equal to the maximum value between $2*D*\varepsilon_{max}$ and 0,5m (Delmas et al. 2015).

3.6 *Anchorage calculation taking into account the progressive mobilization of friction*

From experimental and numerical studies, Briançon and Villard (2008) corrected some of the shortcomings in the existing RAFAEL method. These developments take into account the frictional behavior of the geosynthetic sheet in the anchorage areas by means of a Coulomb friction law. The stretching of the geosynthetic sheet in the anchorage areas leads to an increase of the vertical displacement of the sheet and of the friction together with a change in the orientation of the sheet at the edge of the cavity. For classical values of the friction between soil and geotextile, these developments lead (comparatively to the classic RAFAEL method) to a doubling of the value of the tensile stiffness of the product to insure the surface deflection criterion.

The new design method taking into account these mechanisms has been recently validated on full scale experimentation (Huckert and al., 2016) and DEM simulation (Villard et al., 2016) and could be used for the future designs in this field.

3. CHOICE OF GEOSYNTHETICS

The choice of geosynthetic is done according to several criteria. The two main criteria are the characteristic tensile strength of the product and the nature of the polymer. The product chosen for this project is Geoter® FPVA 400 which has a characteristic tensile strength $R_{t;\,k}$ of 400 kN/m. This value is higher than the ultimate tensile strength R_t calculated with the long term geosynthetic parameters (Equation 2).

The product is made of polyvinyl alcohol (PVA) given its good long-term resistance in the chemical conditions found in a landfill.

4. CONCLUSIONS

The use of geosynthetic reinforcement in order to protect the geomembrane and the waterproofing system of a piggyback landfill in Champigny-sur-Yonne is an attractive solution on technical and economical standpoints.
The RAFAEL method was used to estimate the geosynthetic tensile strength required to retain the loads of the new overlying waste, taking into account the subsidence or collapse of old waste during compaction and consolidation.
This calculation method is to date the most appropriate method for landfill projects but does not allow optimizing the design. Indeed, this method was developed for the case of collapse of a granular soil above sinkholes. However, waste behaves somewhat differently than granular materials (Dixon and Jones, 2005). So, specific studies and tests on the waste should be carried out in order to model the behavior of these materials. In addition, the monitoring of real jobsites by a suitable instrumentation (optical fiber integrated in the geosynthetic reinforcement, settlement sensors, inclinometers, pressure sensors…) could help gather relevant data in order to adapt the classical design methods to the case of landfill expansions and waste materials.

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