History and Future of a Landfill with Non-common Geogrid Reinforcements

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ABSTRACT

The Böschistobel landfill in the western part of Austria is located in a mountainous region and had to be embedded on a hillside. This resulted in an unusual geometry of the planned 70 m high landfill body: one third of the basal system is almost horizontal and two thirds are inclined following the excavated slope of 1v:2h with berms in the hill. In the early 90's the basal system was installed in the horizontal section and on two of the lowest slope sections, inclusive of the geomembrane, and infill of municipal waste started. In 1995-1996 high-strength low-strain geogrids from Aramid (AR) were installed on the two lowest slope sections as "anti-sliding" reinforcement accompanied by a measurement program. In 1996-1997 the rate of infilling of municipal waste decreased significantly. In 2013 the owner decided to reactivate the landfill and to deposit construction debris and/or ashes on top of the old municipal waste, up to the planned height of 70 meters. Detailed multiple stability analyses were performed resulting in a solution with further strong low-strain "anti-sliding" geogrid reinforcement on the slope sections, above those already reinforced in the 90's, and in multilayered geogrid reinforcement with a tensile strength of up to 1200 kN/m directly in the new fill material. The general situation, solution and experience from 1994-1996 are presented followed by a description of the situation, philosophy, design analyses and solutions in the new "reactivation era".

1. INTRODUCTION

For basal and capping systems of landfills multilayered ("sandwich") structures consisting of soils and different geosynthetics are used as State-of-the-art. An overview of solutions in the 90ies can be found already in e.g. Van Impe et al. (1996), the typical German solutions e.g. in Gartung (1995), USA concepts in Koerner (1994) and some alternative solutions e.g. in Alexiew et al. (1995), Alexiew and Sobolewski (1997). All these 'sandwiched systems' have a common characteristic: they comprise some interfaces, in which the shear resistance could be lower than in the soils and geosynthetics themselves. The interface with the lowest resistance controls the sliding stability of multilayered slopes. If the latter is not sufficient, a reliable solution is to lay an appropriate geogrid (say "anti-sliding reinforcement") in the (soil) layers tending to slide on the critical plane. The geogrid has to be installed on the entire slope from the toe up to the crest, and anchored. Figure 1 from Plankel and Alexiew (1998) shows a typical scheme of the problem.

General recommendations being still valid are given e.g. in Alexiew (1994), calculation procedures incl. of the recent concepts among many others in Zornberg et al (2001), Koerner (2005), Alexiew and Sobolewski (2009).

Additionally, for high, steep landfill body geometries, internal, compound and global stability of the fill body could become a problem. From a general point of view it is possible to solve the problem reinforcing the fill by horizontal layers similar to a conventional soil embankment with "oversteep" slopes (called often MSE: mechanically stabilized earth); however, in landfill practice this is a very rare solution.

In the basal system of the Böschistobel landfill in Austria an anti-sliding geogrid solution was implemented in 1995-1996 and also in the recent stage of landfill reactivation in 2013; additionally, layers of horizontal geogrids installed directly in the fill like in MSE are now planned for ensuring its inner and global stability.

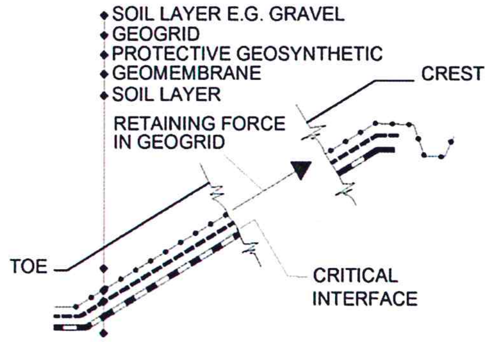


Figure 1. Anti-sliding geogrid reinforcement in a "sandwich" system (Plankel and Alexiew, 1998)

2. THE ANTI SLIDING BASAL REINFORCEMENT 1995-1996

2.1 Overview

The Böschistobel landfill was planned at the beginning of the 90ies. It had to be embedded in a hillside. This resulted in an unusual geometry of the planned ca. 75 m high landfill body: one third of the basal system is almost horizontal and two thirds are inclined following the excavated slope of 1v:2h with berms in the hill (Fig. 2). Each partial slope from berm to berm has a length of 20 m. In 1993-1994 the basal system was installed in the horizontal section and on two of the lowest slope sections, inclusive of the geomembranes, and infill of municipal waste started. At the very beginning only smooth geomembranes were commonly available in the market in Austria, thus they were installed on huge parts of the basal system before switching to a textured one in the 2nd berm (Fig. 2).

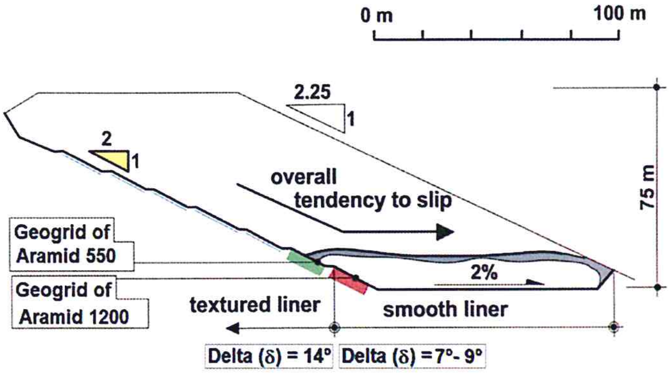


Figure 2. Typical cross-section of the Böschistobel landfill, level of municipal fill in 1995, overall tendency to slide and shear angles "delta" in the critical basal interfaces

In 1995 doubts about the global sliding stability of the landfill arose. Interface shear angles - named herein "delta" - were precisely tested. As a critical interface the contact protective geosynthetic (non-woven) to geomembrane (compare Fig. 1) was identified. Delta = 7°- 9° and 14° were evaluated as design values for the smooth and textured geomembrane (liner), respectively (Fig. 2). Stability analyses for the global sliding of the entire landfill body on the basal system using common polygonal shear plane methods as Janbu resulted in insufficient stability for both the actual state in 1995 and probable future infill stages as well. Significant retaining "anti-sliding" forces of more than 800 kN/m design value as per 1995 had to be provided by implementing "anti-sliding" reinforcement to ensure global sliding stability. At the same time the intervention in the "status quo" (already existing basal system and municipal fill, Fig. 2) had to be minimized.

It was decided to excavate the municipal fill only over the inclined (slope) basal zones and to install geogrids starting at the first and the second partial slopes.

Note, that the internal fill body stability was at that time not an issue: the general unsorted municipal waste in Austria included a huge amount of plastics providing, according to German research as "dispersive reinforcement", a significant long-term isotropic "equivalent cohesion"; compare in this context the situation after landfill reactivation in 2013 below.

2.2 "Anti-sliding" geogrids in 1995-1996

Significant retaining forces had to be provided over relatively short stretches (the two first partial slopes of 20 m each, Fig. 2) in comparison to the global geometry of the landfill. The owner had to be convinced that only geogrids are a proper solution and that the job cannot be done by similar (but cheaper) high-strength woven geotextile (as it was unfortunately written e.g. in Koerner, 1994 and later in Mannsbart, 1996). The point is that optimized geogrids ensure a sufficient bond to the mineral layers - which is critical for "anti-sliding" reinforcement - in opposite to wovens, which can even create an additional problematic interface due to their smoothness; see also e.g. (Alexiew, 1994, Martin and Simac, 1995, Alexiew and Sobolewski, 1997, 2009).

Despite the high strengths needed, strains i.e. elongations had to be kept as low as possible, see e.g. Long (1994). Finally geogrids from Aramid (AR) were chosen also due to their very high tensile stiffnes (say low strains) in the short-term and after creep as well: Fortrac® 1200/50-10 A and Fortrac® 550/100-30 A with an ultimate tensile strength (UTS) of 1200 kN/m and 550 kN/m, respectively, and ultimate strain < 3 % (Fig. 3). They had been produced and used for the first time for bridging sinkholes (Alexiew, 1997).

However, this was the first time worldwide when aramid geogrids were used in a landfill to meet extreme requirements in terms of strength and strains, and was an innovative application.

a b c

Figure 3. a: tension vs. strain for the aramid geogrids used in 1995-1996; b: installation of geogrids on the first partial slope; c: heavy anchoring trench due to the high tensile forces

For more details regarding design, philosophy, arguments and final solution in 1995 see Plankel and Alexiew (1998). (Note that at that time another possible sound alternative such as high-strength low-strain low-creep geogrids from Polyvinylalcohol (PVA) were still not available (Alexiew et al, 2000)).

2.3 Measurements in 1996-1997

A measurement program was installed on the first and second partial slopes (Fig. 2). Strains of the geogrids and pressures above them were registered. The geogrids behaviour met in general the design prognosis; the mobilized strains (say tensile forces) followed the waste surcharge (Fig. 4). For more details and comments see Plankel and Alexiew (1998).

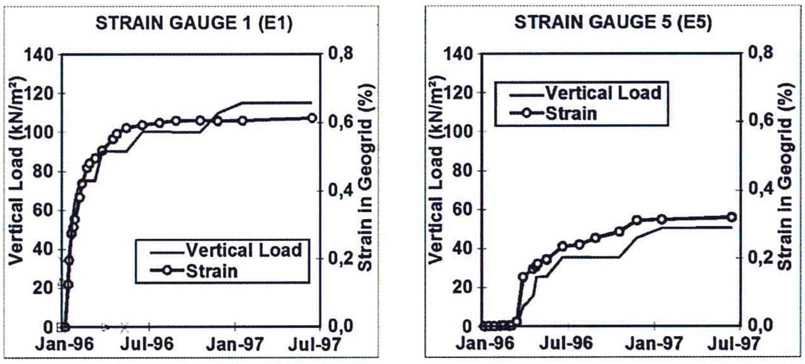


Figure 4. Examples of tensile strains in the geogrids following the waste surcharge

3. STABILITY ANALYSES PERFORMED IN 2013

3.1 Overview

In 1997-1998 the law regulating waste management and disposal in Austria changed. A strict waste separation started. The amount of the unsorted general municipal waste decreased enormously. The Böschistobel landfill being certified for this purpose became practically inactive. By the way, due to that 3P Geotechnik was (unfortunately) told to stop the measurements mentioned above. Starting in 2005 some construction debris and ashes were allowed to be deposed, but of marginal volume without influence on the design, analyses and solutions from 1995-1996. In 2009 the licence of the landfill was officially modified permitting the deposit of construction waste and slag and ashes from waste incineration, but only marginal volumes were deposed. In 2013 the effective and planned amount of such fills increased quickly and significantly, a landfill reactivation era began.
Thus, in 2013 new stability analyses had to be performed to adapt the stability of landfill to the changing conditions - now and in future. Note, that even for the so called construction waste the constituents changed over the years and can continue changing in future, which results in different density and shear resistance. Also the relation and volumes of

construction waste, slag and ashes can change. These circumstances play a key role in the multiple stability analyses, philosophy and flexibility concept described below.

3.2 Models and modes for the stability analyses

3.2.1 Geometry and different waste deposition assumptions

The general landfill geometry - height, slopes, berms etc. - remains the same as planned beginning of the 90ies (Fig. 2). At that time the entire waste body was foreseen to consist of municipal waste. This changed now: above the old municipal waste construction debris, slag and ashes will be deposed. Periods, sequences and volumes are not exactly predictable: the final quantity and distribution of the materials in the landfill body is uncertain. At present two "waste disposal" assumptions were made based on two most probable scenarios, in order to perform local and global stability analyses. The profile is shown in Figure 5. Two possible borders between the demolition waste and the slag were defined. The Assumption 2 considers a higher percentage of slag than the Assumption 1.

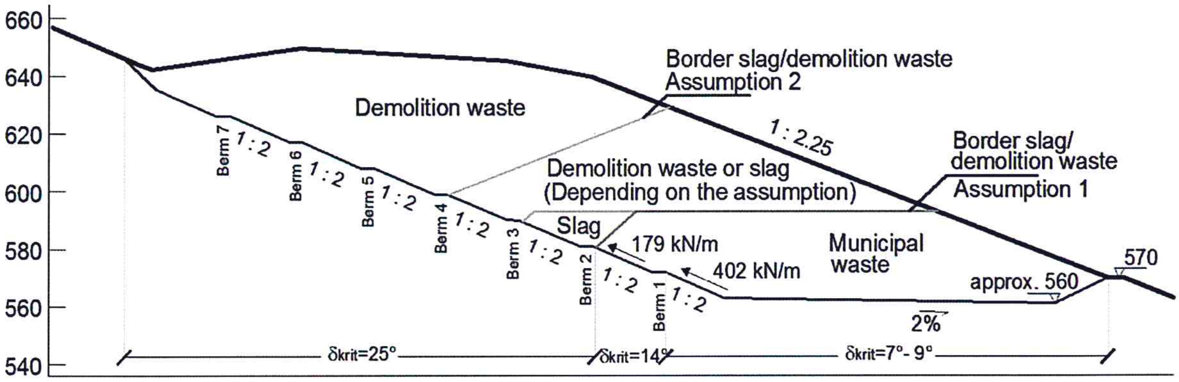


Figure 5. Model used for stability analysis in 2013 with two waste disposal assumptions

3.2.2. Stability/failure modes analyzed

In 1995-1996 only the global "external" sliding stability of the waste body on the contact/interface to the basal system was from interest (Chapter 2.1). In 2013 the "internal" or "compound" stability - say failure surfaces also crossing the waste body - became important as well, due to the new types of waste foreseen. The "external" global sliding is called now herein Mode1, and the "internal" resp. "compound" failure is called Mode 2.

3.3 Stability analysis

3.3.1 General

The stability analyses were carried out by means of the software GGU Stability (2013) according to the Eurocode 7 (2011) and the partial factors stipulated in the ÖNORM EN 1997-1 (2010). A degree of utilisation (μ) smaller than or equal to 1.0 has to be obtained to ensure the required safety level.
Several possible slip surfaces were analysed in order to determine the most unfavourable mechanism. For Mode 1 polygonal slip surfaces were analysed using the vertical slice method similar to Janbu, and for Mode 2 both polygonal and circular slip surfaces (Bishop).

3.3.2 Geomechanical parameters

To determine the critical sliding interface along the base, the shear resistance at the contact between the successive layers was compared. According to the available information and the experience in similar projects the contact soil layer (clay liner) / geomembrane (Fig. 6) was identified as critical interface. A possible adhesion between these two layers was neglected.
The parameters of the landfill body and of the critical basal interface used for the calculations are shown in Table 1.

Table 1: Geomechanical parameters of the model

Material	Angle of friction internal/interface φ'/δ' [°]	Cohesion/Adhesion c'/a' [kN/m²]	Unit weight γ [kN/m³]
Municipal solid waste	25.0	25.0	14.0
Slag (waste incineration)	35.0	3.0	18.5
Demolition waste	40.0	1.0	16.0
Interface between geomembrane / clay liner	25.0	0.0	1.0 (assumed due to calculation reasons only)

A fictive thin layer was introduced in the model to simulate the interface between the geomembrane and the clay liner. This layer was modelled with an internal angle of friction equal to the δ-value mentioned in Table 1. The cohesion of the layer was assumed to be zero like the assumed adhesion at the interface. The unit weight of this layer was set to 1 kN/m³.

The existing geogrids, installed in the 90's, were modelled as concentrated loads acting upwards parallel to the slopes (Fig. 5). The value of this forces were assumed as ~400 kN/m for the geogrid on the first partial slope and ~180 kN/m for the geogrid on the second one. These values correspond to the long-term design strength of the aramid geogrids used.

3.4 Results

Stability was analyzed for both the waste Assumptions 1 & 2 (Chapter 3.2.1) and for both failure Modes 1 & 2 (Chapter 3.2.2). Also different Stages of waste filling (construction steps) between the present and final waste height were checked to gain an overview of safety levels and their stage-dependency. For all cases the stability was not sufficient; the degree of utilisation (μ) was > 1.0 (Chapter 3.3.1). The stability deficit increased generally with increasing height for all Assumptions and Modes. For Mode 2 the critical failure geometry consisted typically of polygonal shear planes crossing the waste body and continuing on the basal interface similar to Figure 8. In any case not an internal circular or internal polygonal, but a compound polygonal Mode 2 controls the stability.

According to this results, the licensed deposit volume (landfill capacity) cannot be utilized without further stabilisation measures.

3.5 Measures to reach the required stability

The installation of additional geogrids to reach the required safety level was proposed, in view of the reliability shown by the anti-sliding reinforcements used in the previous stages of this project. The difference to 1995-1996 is that now not only the Mode 1 (external global sliding on the base) but also the Mode 2 (compound failure) have to be handled. Further multiple stability analyses were carried out considering different geogrids. They followed the logic of the non-reinforced studies (Chapter 3.4) in terms of Assumptions, Modes and stages.

3.5.1 Reinforcement for Mode 1

The solution is a typical "anti-sliding" geogrid reinforcement analogue to the solution from 1995-1996 (Figs. 1, 2 & 6 left). Limitation of strains was again an issue to minimise the risk of elongation and failure of the geomembrane (GBM). The difference to 1995-1996: not Aramid (AR) was chosen as geogrid polymer, but Polyvinylalcohol (PVA), mobilizing also high tensile forces at low strains (Fig. 6 right) and being in the same time of higher chemical resistance.

The retaining (anti-sliding) tensile forces provided by the geogrids were modelled as concentrated loads (vectors parallel to the basal slopes). Their value was then incrementally increased until the obtained degree of utilisation was smaller than 1.0, say until reaching sufficient stability. This value is nothing else than the required design tensile strength of the geogrids. The required ultimate short term tensile strength (UTS) was then back-calculated applying reduction and partial safety factors. One final print-out example of calculations is shown in Figure 7.

The PVA-geogrids chosen are Fortrac® 1300 MPT with an UTS = 1300 kN/m at a strain of < 5 %.

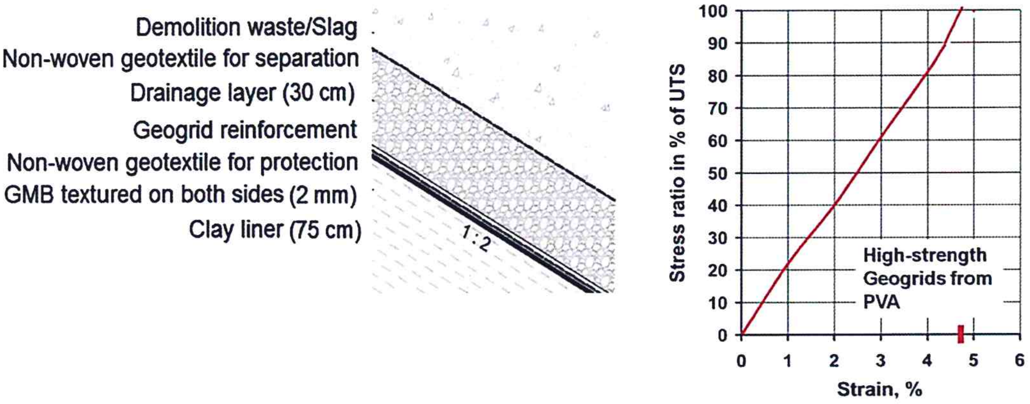
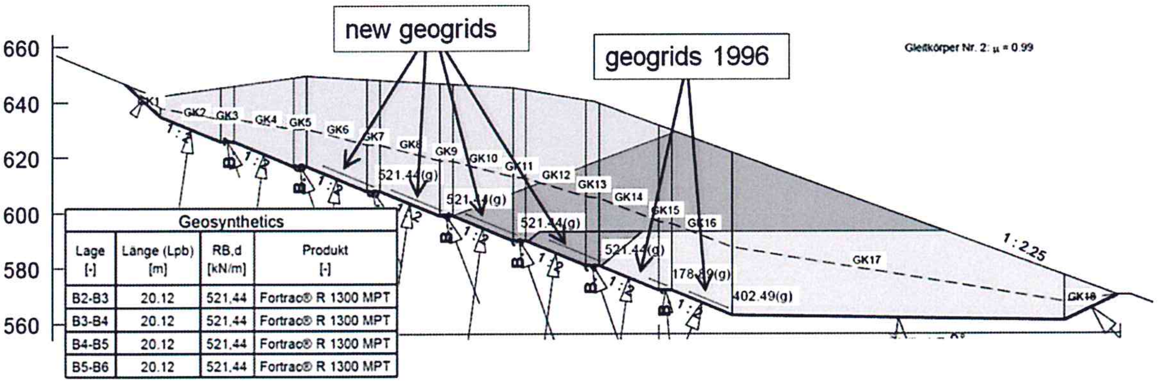


Figure 6. Basal system (left) and stress vs. Strain for PVA-geogrid (right)

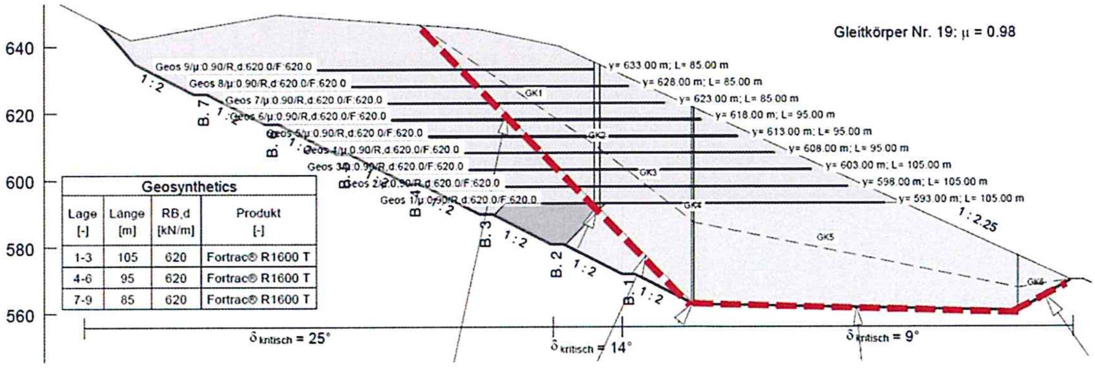


Geosynthetics			
Lage [-]	Länge (Lpb) [m]	RB,d [kN/m]	Produkt [-]
B2-B3	20.12	521,44	Fortrac® R 1300 MPT
B3-B4	20.12	521,44	Fortrac® R 1300 MPT
B4-B5	20.12	521,44	Fortrac® R 1300 MPT
B5-B6	20.12	521,44	Fortrac® R 1300 MPT

Figure 7. Example of stability calculation for waste Assumption 2, failure Mode 1, final height

3.5.2 Reinforcement for Mode 2

The MSE-principle was applied (Chapter 1). Horizontal geogrid layers are foreseen to avoid a failure across the landfill body (Fig. 8).



Geosynthetics			
Lage [-]	Länge [m]	RB,d [kN/m]	Produkt [-]
1-3	105	620	Fortrac® R1600 T
4-6	95	620	Fortrac® R1600 T
7-9	85	620	Fortrac® R1600 T

Figure 8. Example of stability calculation for waste Assumption 2, failure Mode 2, final height with horizontal multilayered geogrid reinforcement

The vertical spacing of 5 m is much more bigger then typically 0.4 to 0.6 m in conventional MSE, to minimize the impact of this reinforcement measure on the operation of the landfill. Note that the geogrids end to the right some meters away from the surface of the final waste body to allow an easy and qualified finalization of the future capping system.
For this case the strain limitations are less strict in comparison to the situation on the slopes with the geomembranes. Further on, slag and construction waste are as fill stiffer than e.g. municipal waste. Consequently, geogrids Fortrac® 1600 T from high-tenacity Polyester (PET) with an UTS = 1600 kN/m at ca. 9 % strain are chosen, say, of higher strength but also of higher extensibility then the PVA-geogrids on the slopes.

3.5.3 Construction steps resp. fill stages

As mentioned in Chapter 3.4, all stability analyses were performed not only for the final situation, but also for a multi-staged construction process of some yers. The types, position and geometry of the geogrids shown in Figs. 7 & 8 were optimized in such a way that they ensure the stability in both Modes 1 & 2 also for all possible construction stages. Due to brevity this optimization procedures cannot be shown or commented herein in detail.

4. FLEXIBILITY OF THE CONCEPT

The present geogrid reinforcement solutions for the Mode 1 "external global sliding" and Mode 2 "compound failure" are optimized according to the current plans of landfill use covering two different waste disposal scenarios and a multi-staged infill process. However, since the geogrids for Mode 1 will be installed slope by slope (berm to berm, Fig. 7) and for Mode 2 after every 5 m of waste (Fig. 8), the types of geogrids can be easily changed to adapt future scenarios and types of waste differing from the plans today.
In November 2013 the installation of the new geogrids started on the third slope, being the first one with "new" geogrids after 1995-1996 (Fig.7).

5. SUMMARY

The landfill Böschistobel in Austria was constructed and put into operation at the beginning of the 90ies as a landfill exclusively for municipal waste. Geometry and position in a hilly area are quite specific. In 1995-1996 aramid geogrids with up to 1200 kN/m strength were installed as "anti-sliding" reinforcement to ensure the global sliding stability of the entire waste body. A measurement program confirmed the plausibility of the solution. Then for about 15 years the landfill had been practically inactive. A reactivation era started in 2013 for other types of waste. New series of stability calculations were performed varying waste disposal scenarios, failure modes and infill stages. Based on the positive experience in the 90ies in terms of efficiency and proper system behaviour, geogrid solutions were taken into consideration again. High-strength geogrids from Polyvinylalcohol (PVA) and Polyester (PES/PET) with up to 1600 kN/m strength are foreseen and started being installed.

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