# Landfill and Contaminated Land

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# A landfill with innovative reinforcing solutions: history, experience, solution flexibility

## Un ISDN avec solution de renforcement innovante: histoire, expérience, solutions flexible

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ABSTRACT A landfill in a mountainous region of Austria is embedded on a hillside. This results in an unusual geometry of the planned 75 m high landfill body: one third of the basal system is almost horizontal and two thirds are inclined following the excavated slope 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 and infill of municipal waste started. In 1994 doubts were raised regarding the local and global stability. High-strength low-strain geogrids from Aramid (AR) were installed in 1995-1996 on the two lowest slope sections as "anti-sliding" reinforcement. In the late 90ies the infilling of municipal waste almost stopped. 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 75 meters. 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. The general situation, solution and experience from 1994-1996 are presented followed by a description of the situation, philosophy, design analyses and solutions today demonstrating how innovative geosynthetic reinforcements can help to solve specific landfill stability problems.

RÉSUMÉ Un ISDN dans une région montagneuse de l'Autriche a été implanté sur un versant de la colline. Cela aboutit à une géométrie inhabituelle du corps de décharge de 75 m de haut : un tiers du système à la base est presque horizontal et les deux tiers sont inclinés selon la pente creusée dans la colline. Au début des années 90, la section horizontale et deux des sections inclinées les plus basses ont été installées et le remplissage d'ordure ménagère a commencé. En 1994, les premiers doutes ont été levés quant à la stabilité locale et globale. Des géogrilles de haute résistance et à très faible allongement à base d'Aramide (AR) ont été installées dans les années 1995-1996. Elle avait un rôle de reprendre les efforts de glissement latéraux le long des pentes. A la fin des années 90 , la collecte des déchets ménager à fortement diminué à cause du tri sélectif et l'ISDN a arrêté son activité. En 2013, le propriétaire a décidé de réactiver la décharge et de déposer des débris de construction et/ou des cendres directement au-dessus des déchets ménager, jusqu'à la hauteur planifiée de 75 mètres. Des analyses de stabilité multiples ont été exécutées aboutissant à une solution avec de nouvelle géogrille de renfort "anti-glissante" à très faible allongement sur les sections inclinées, au-dessus de ceux déjà renforcés dans les années 90. De plus, plusieurs couches de géogrille de renfort de résistance à la traction jusqu'à 1200 kN/m sont nécessaires dans le corps de la décharge afin d'assurer la stabilité globale. La situation générale, la solution et l'expérience de 1994-1996 sont présentés. La philosophie, l'analyse de la conception et des solutions démontrant comment aujourd'hui, des géogrilles de renforts innovantes peuvent aider à résoudre des problèmes de stabilité de décharge spécifiques

## 1 INTRODUCTION

For basal and capping systems of landfills multilayered ("sandwich") structures consisting of soils and different geosynthetics are state-of-the-art. A first world-wide overview of typical solutions in the 90ies can be found already in e.g. Van Impe et al. (1996), typical German solutions e.g. in Gartung (1995), USA concepts in e.g. 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/or in the geosynthetics themselves. The interface with the lowest resistance in an inclined "sandwich" controls the sliding stability. If the latter is not sufficient, a reliable solution is to install an appropriate geogrid (say "anti-sliding reinforcement") typically in the mineral drainage layer. The geogrid has to be installed on the entire slope and anchored. General recommendations being still valid are given e.g. in Alexiew (1994), calculation procedures incl. of the recent concepts among many others in Koerner and Soong (1998), Alexiew and Sobolewski (1997, 2009), Zornberg et al (2001), Palmeira and Viana (2003), Koerner (2005), Russo (2008).

Additionally, for high, steep landfill body geometries, internal, compound and global stability of the fill body could become a problem beside the flat sliding in the "sandwich" mentioned above. It is possible to solve this problem reinforcing the fill by horizontal geogrid layers similar to a conventional soil embankment with "oversteep" slopes (called often MSE: mechanically stabilized earth); however, in landfill practice this is a rare solution.

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

## 2 THE ANTI SLIDING BASAL REINFORCEMENT 1995-1996

### *2.1 Overwiew*

The Böschistobel landfill was planned at the beginning of the 90ies and is embedded in a hillside. The consequence is an unusual geometry of the ca. 75 m high landfill: one third of the basal system is only slightly inclined (almost horizontal) and two thirds are inclined following the excavated slope of 1v:2h with berms in the hill (Fig. 1). Each partial slope has a length of 20 m. In 1993-1994 the basal system was installed in the bottom section and on two of the lowest slope sections, inclusive of the geomembranes, and infill of municipal waste started.

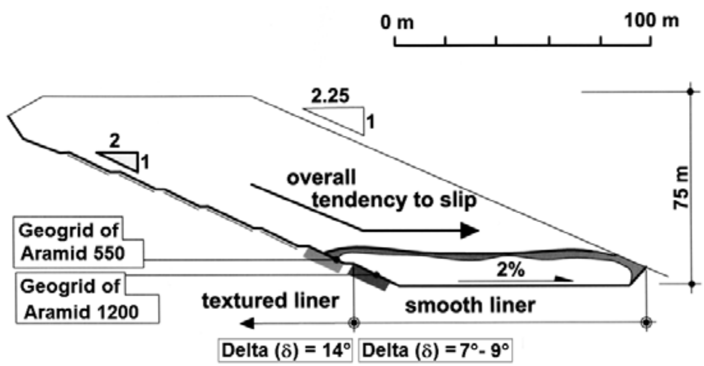


**Figure 1.** Typical cross-section of the Böschistobel landfill, level of municipal fill in 1995, overall tendency to slide and shear angles "delta" in the critical basal interfaces

At the beginning only smooth geomembranes were commonly available in Austria, thus they were installed on huge parts of the basal system before switching to a textured one on the 2$^{nd}$ slope (Fig. 1).

In 1995 doubts about the global sliding stability of the landfill on the basal "sandwich" arose. Interface shear angles δ were rechecked again. The interface protective geosynthetic (non-woven) to geomembrane was identified as the critical one with design δ-values varying from 7° to 9° and 14° for the smooth and textured geomembranes, respectively (Fig. 1). Stability analyses for the sliding of the entire landfill body on the basal system resulted in insufficient stability for both the actual state in 1995 and probable future infill stages as well. Significant retaining forces had to be provided by "anti-sliding" reinforcement to ensure sliding stability. 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 (Fig. 1).

Note, that the internal fill body stability was at that time not a point: the unsorted municipal waste included a huge amount of plastics as "dispersive reinforcement" providing a significant isotropic "equivalent cohesion"; compare in this context the different situation after landfill reactivation in 2013 below.

### *2.2 "Anti-sliding" geogrids in 1995-1996*

Huge retaining forces had to be provided over the two first partial slopes of 20 m each (Fig. 1). Optimized geogrids had to be used to ensure also a sufficient bond to the drainage layer, which is critical for "anti-sliding" (Alexiew, 1994, Martin and Simac, 1995, Alexiew and Sobolewski, 1997, 2009). Strains i.e. elongations had to be kept as low as possible due to strain compatibility (Long 1994) and stringent limitations of geomembrane strains. Finally geogrids from Aramid (AR) were applied due to their very high tensile stiffnes (say low strains): Fortrac® 1200/50-10 A and 550/100-30 A with an ultimate tensile strength (UTS) of 1200 kN/m and 550 kN/m, respectively, and ultimate strain < 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.

Note that at that time other sound alternatives like e.g. high-strength low-strain geogrids from Polyvinylalcohol (PVA) were still not available (Alexiew et al, 2000).

A comprehensive measurement program was installed on the first and second partial slopes confirming the correctness of the solution.

For more details see Plankel & Alexiew (1998).

## 3 REACTIVATION IN 2013

### *3.1 Overview*

In 1997-1998 the amount of municipal waste in Austria decreased enormously. The Böschistobel landfill became practically inactive.

In 2009 the licence of the landfill was officially modified permitting the deposition of construction waste, slag and ashes from waste incineration. In 2013 the effective and predicted amount of such fills increased quickly, a real landfill reactivation era began. Thus, in 2013 new stability analyses had to be performed to adapt the stability of landfill to these changes - now and in future. Note that the relation and volumes of construction debris, slag and ashes having different parameters can change. This circumstance led to the multiple stability analyses, the 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 remains the same as planned beginning of the 90ies (Fig. 1), but 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 most probable scenarios are assumed, in order to perform stability analyses. They are shown in Figure 2. The Assumption 2 considers a higher percentage of slag than the Assumption 1.

#### *3.2.2 Stability/failure modes analyzed*

In 1995-1996 only the global "external" sliding of the waste body on the contact/interface to the basal system was from interest. In 2013 the "internal" or "compound" stability - say also failure surfaces 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 analyses*

#### *3.3.1 General*

The stability analyses were carried out according to the Eurocode 7 (2011) and the partial factors stipulated in the ÖNORM EN 1997-1 (2010).

Several possible slip surfaces were analysed: for Mode 1 polygonal slip surfaces using the vertical slice method similar to Janbu, and for Mode 2 both polygonal and circular slip surfaces (Bishop).

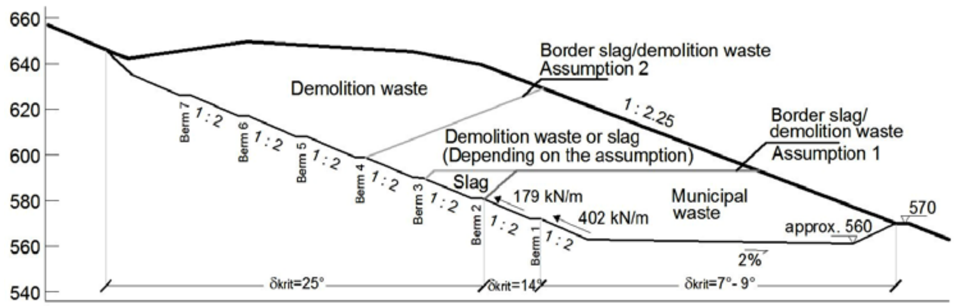


**Figure 2.** Model used for the stability analyses in 2013 with two different waste disposal assumptions

### 3.3.2 *Assumed relevant parameters*

The assumed design parameters are summarized in Table 1. Note, that on the contrary to 1995-1996 the critical interface is now due to the application of a double-sided textured geomembrane the contact at its bottom side, say geomembrane/clay liner.

The existing geogrids, installed in the 90's, were modeled as concentrated loads acting upwards parallel to the slopes (Fig. 2). Due to the lack of space further calculation details cannot be explained herein.

## 3.4 *Results*

Stability was analyzed for both the waste Assumptions 1 & 2 and for both failure Modes 1 & 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 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 4. In any case not an internal circular or internal polygonal, but a compound polygonal Mode 2 controls the stability.

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

**Table 1:** Geomechanical parameters of the model

| Material | Angle of internal friction /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) |

## 3.5 *Measures to reach the required stability*

The installation of additional geogrids to reach the required safety level was proposed. 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 in the fill) have to be handled. Further multiple stability analyses were carried out considering different geogrids. They followed the logic of the non-reinforced studies 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 (Fig. 1). Limitation of strains was again a key issue. The difference to 1995-1996: not Aramid (AR) was chosen as geogrid polymer, but Polyvinylalcohol (PVA), mobilizing also high tensile forces at low strains (Alexiew 1997) and being in the same time of higher chemical resistance. The retaining (anti-sliding) tensile forces provided by the geogrids were modelled as vectors parallel to the basal slopes. Their value was then incrementally increased 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 3.

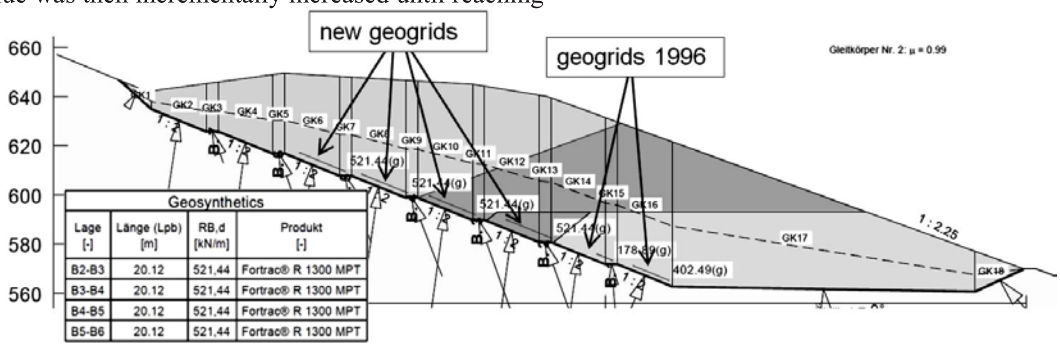


**Figure 3.** Example of stability calculation for waste Assumption 2, failure Mode 1, final height

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

### 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. 4). 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 above, all stability analyses were performed not only for the final situation, but also for a multi-staged construction process of some years. The types, position and geometry of the geogrids shown in Figs. 4 & 5 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 and for Mode 2 after every 5 m of waste, 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.3).

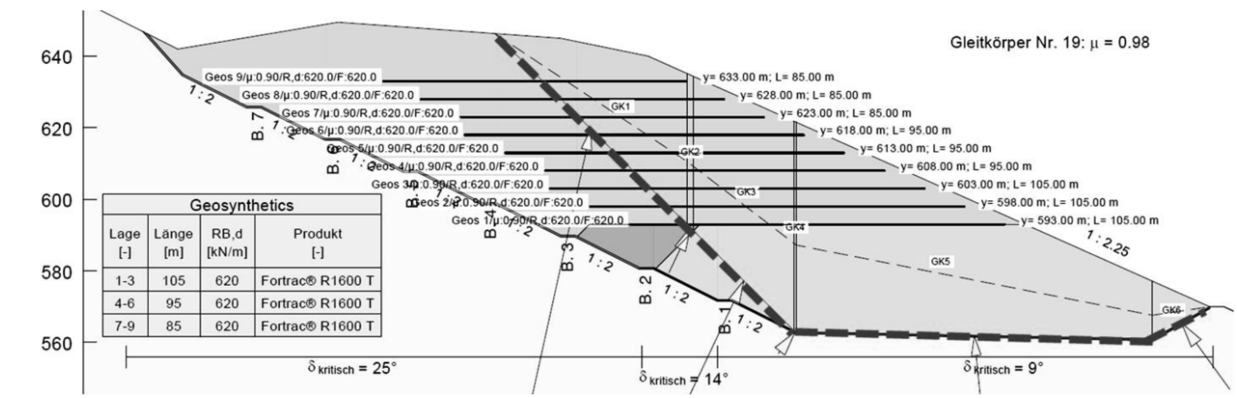


**Figure 4.** Example of stability calculation for waste Assumption 2, failure Mode 2, final height with horizontal multilayered geogrid reinforcement

## 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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