The use of geosynthetics in steep side wall capping: A case study

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ABSTRACT: A ferrochrome smelter in South Africa is in the process of upgrading its waste management facilities to comply with the requirements of local legislation. As part of this process, a previously decommissioned hazardous waste facility required an upgraded capping design. The facility was originally decommissioned and capped in 1999, with a geomembrane covered by a protective layer of slag fines on the top surface, while the steep outer slopes were capped with concrete filled geocells. Due to settlement of the waste body, the existing concrete cap on the side slopes has cracked, while some areas have been subject to mechanical damage. This paper presents the engineering solution applied to effectively upgrade the cap with particular focus on the steep (1V:1.5H) side slopes and the use of geosynthetics to overcome the associated stability challenges. Given the space constraints at the site, the side slopes had to be capped without significant modification to their shape. This, coupled with the requirement for a geomembrane with appropriate protective cover on the slopes, presented challenging design criteria. The design includes a protection geotextile placed over the existing concrete surface on the side slopes, which is covered by the HDPE geomembrane. A specialised geogrid was included to carry the load of the cover soil over the geomembrane. The geogrid is bonded to a textured geomat which provides adequate friction forces to hold the cover soil in place. The design represents a feasible and effective geosynthetic solution.

Keywords: Steep capping, geosynthetic reinforcement

1 INTRODUCTION

Capping of steep side slopes is a challenge often encountered by design engineers. Space constraints as well as the maximisation of airspace at expensively lined waste disposal facilities are common reasons for requiring steep side slope capping. In these scenarios, an appropriate combination of geosynthetics and natural materials can provide an effective and feasible solution to encapsulate a waste body.

This paper presents the case of an existing decommissioned and capped hazardous waste containment facility (herein referred to as the Capped Facility) which required an upgraded capping design in order to meet the applicable minimum requirements for closure of the site and ensure long term environmental protection. The Capped Facility, which is located at a major ferrochrome smelter in South Africa, has existing side slopes of 1(V):1.5(H), providing a challenge for in-situ encapsulation which is ideally undertaken on slopes not exceeding 1(V):3(H).

1.1 *Background*

The ferrochrome smelter plant consists of six submerged arc furnaces, a Chrome Recovery Plant and a Pelletising and Sintering Plant. The ferrochrome production process generates Electric Arc Furnace (EAF) dust, some of which is pelletised and re-processed through the arc furnaces, whilst the remainder is currently transported and disposed at a licensed hazardous waste disposal facility. The EAF dust is hazardous due to the presence of hexavalent chromium (Cr^{6+}) and can cause groundwater pollution if not managed and disposed of in an appropriate manner.

The unlined Capped Facility received EAF dust until it was decommissioned and initially capped in 1999 to prevent the ingress of precipitation, which was identified as a potential cause of groundwater contamination. Subsequently, in order to gain licensed approval for the decommissioning of the site, the decision was taken to upgrade the existing cap in accordance with the requirements of updated local legislation, namely the National Environmental Management: Waste Act (Act 59 of 2008) and particularly the recently promulgated National Norms and Standards for Disposal of Waste to Landfill (Department of Environmental Affairs, 2013).

1.2 *Objectives*

The objective of this paper is to provide insight into an effective geosynthetic solution for the capping design of an existing unlined hazardous waste facility with steep side slopes. In order to be effective, the design needed to provide appropriate long term, legally compliant environmental protection (within the context of local legislation), while remaining feasible in terms of costs, constructability and on-going operations at the smelter.

2 THE EXISTING FACILITY

Prior to its decommissioning, EAF dust was deposited at the Capped Facility site within a perimeter berm made up of slag. In 1999, the 5 hectare facility was closed and capped on its top surface with a 1 mm thick HDPE geomembrane liner, covered with a protective layer of slag fines. The steep outer slopes of the facility were capped with concrete filled geocells, with the length of the slopes varying from 5 to 25 m. The top surface was given a concave shape and sloped towards the south-west corner of the facility to a drainage inlet structure. This structure drained surface water from the top of the facility through a steel and HDPE pipe to discharge through the base of the slag berm into a perimeter toe-drain. The concrete lined toe-drain was constructed around the base of the facility to drain stormwater runoff.

Due to the settlement of the waste body over time, the concrete capping system has cracked or deformed in certain areas. Mechanical damage has also occurred as a result of operational activities at an adjacent slag dump. The existing capping system therefore does not provide a low permeability barrier against water ingress. The need for an upgraded cap to prevent the ingress of stormwater is therefore evident, as depicted in the Figures 1 and 2.

3 SITE CONDITIONS

The Capped Facility is located at the foot of a mountainous area where both surface water and groundwater are naturally channelled towards the site, in the direction of a nearby perennial river.

Average Temperatures in the area vary from minimums of 4°C in winter to maximums of 32°C in summer. The Mean Annual Precipitation (MAP) for the area varies from 550 to 580 mm, however this is characterised by intense thunderstorms during the summer months.

According to the 1:250 000 Geological Map of the region, the site is underlain by coarse grained norite and gabbro with subordinate anorthosite, with interlayered black magnetite gabbro, pyroxinite and anorthosite layers. These are all part of the Rustenburg Layered Suite of the Bushveld Igneous Complex. There are also dolerite intrusions present in the area.

Geotechnical investigations on the land adjacent to the Capped Facility revealed that granular soil was available for use as cover material on the upgraded cap. It should be noted that new slag disposal facilities are to be constructed on the land adjacent to the Capped Facility, and it was therefore considered feasible to use this material for this purpose.

Figure 1. Southern embankment and perimeter drain of existing Capped Facility.

Figure 2. Large cracks in the existing capped side slopes.

4 DESIGN OVERVIEW

In order to promote runoff away from the Capped Facility and eliminate the potential for ponding, it was decided to create a convex “dome” shape on the top surface prior to capping. The domed shape is achieved through the placement and compaction of waste residues from elsewhere in the Smelter complex, on the top surface to create a 1(V):10(H) slope, with the high point located centrally. The existing drain inlet on the top surface is to be permanently blocked prior to the construction of the dome.

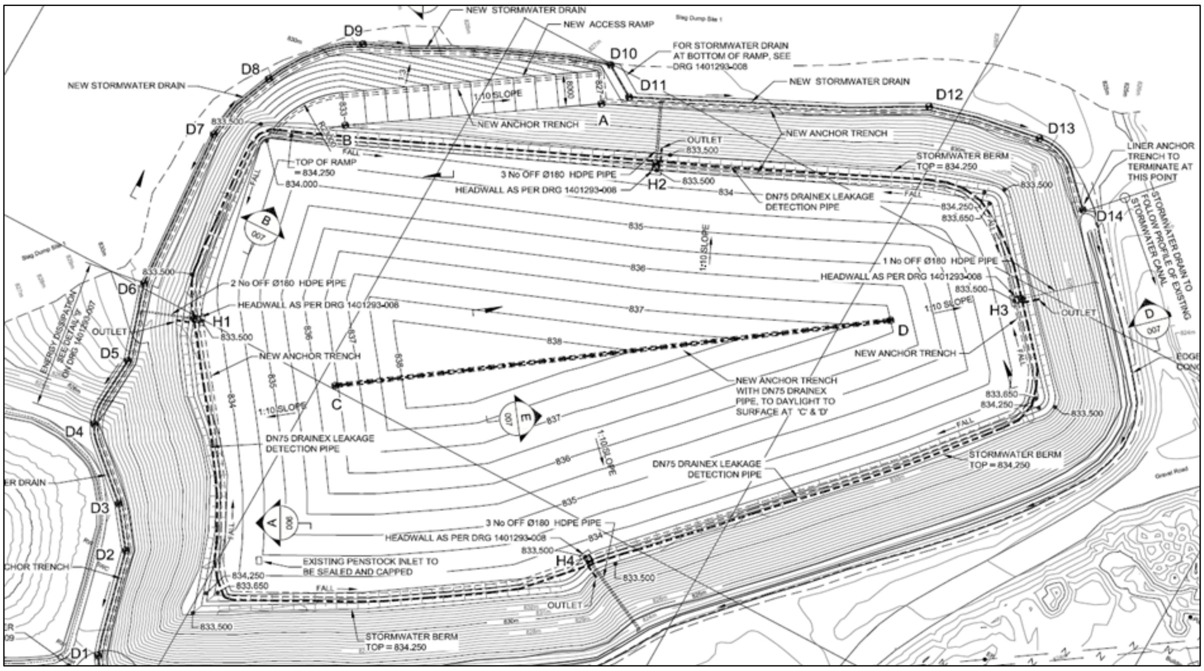

Figure 3. Design overview.

The top surface capping was designed to be placed immediately above the “dome”, while the steep side slopes would require localised repairing of the existing concrete filled geocell surface to remove any sharp protrusions and to fill any voids. The stability of the steep side slope capping design was confirmed by conducting a veneer stability analysis. It should be noted that the decision to design an upgraded cap without significant modification to the gradient of the side slopes was taken for various reasons. The primary reason, however, was due to space constraints around the Capped Facility, with existing and planned new waste facilities as well as power lines located in the immediate vicinity.

In order to reduce uncontrolled surface runoff over the steep side walls of the facility, dedicated down-pipes at selected locations were included in the design. Stormwater runoff will drain away from the high point and be directed to the dedicated downpipes by an earth berm running around the top surface of the facility. These pipes drain into the concrete perimeter drain located around the toe of the facility. The concrete perimeter drain was also upgraded in this design to tie into the new proposed capping system. Furthermore, the drain provides anchorage at the toe of the side walls for the capping system.

To account for potential groundwater seepage into the base of the facility a subsurface “curtain drain” within a cut-off trench was included in the design. The curtain drain is located outside of the Capped Facility’s footprint in an optimum location to intercept groundwater prior to it entering the contaminated area.

5 GEOSYNTHETIC CAPPING SOLUTION

5.1 *Top Surface Capping Design*

Given the lack of a basal lining system at the hazardous waste containing Capped Facility, more stringent capping design requirements were imposed by the local Regulator. In order to comply with these requirements, a composite liner system had to be designed for the cap in order to ensure adequate containment of the waste.

Figure 4 presents the design of the capping system for the flatter domed area of the Capped Facility, which comprises the following layers (from top downwards):

– 300 mm thick topsoil with grass;
– Geocomposite drainage layer;
– 1.5 mm thick HDPE geomembrane liner (double textured);
– Cuspated HDPE sheet leakage detection and drainage layer, with a collection pipe (75 mm diameter slotted HDPE pipes) around the top surface perimeter;
– 1.5 mm thick HDPE geomembrane liner (double textured); and
– Geotextile protection layer placed on the surface of the compacted slag residues.

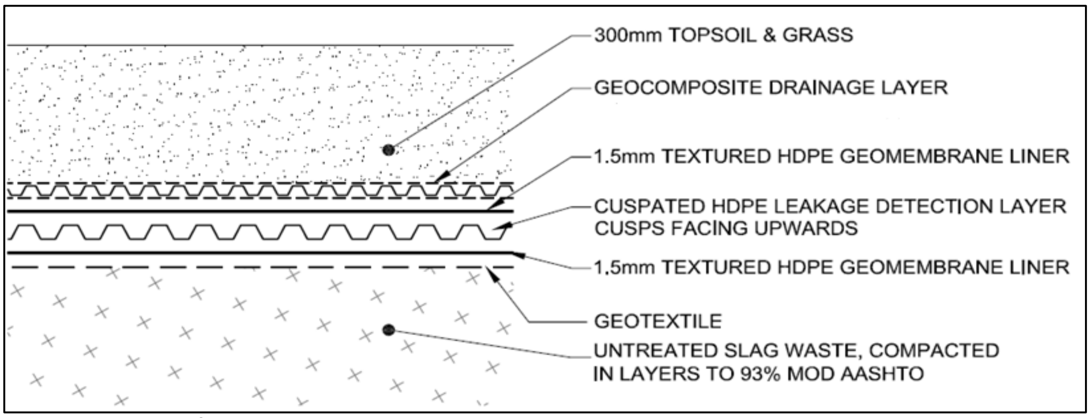

Figure 4. Top surface capping system.

This capping barrier design is considered an equivalent composite liner design. Due to the lack of availability of clay material on or near to the site, the clay layer was replaced by a secondary geomembrane with a leakage detection and drainage layer. The leakage drainage layer, which also acts as a hydraulic breaker layer, is located between the two geomembrane layers. Pipes within this layer are located around the perimeter of the top "dome" to collect any leakage. T-joints are located at certain points on this upper perimeter to discharge the leakage out of the capping system and over the side slopes of the facility, as presented in Figure 5.

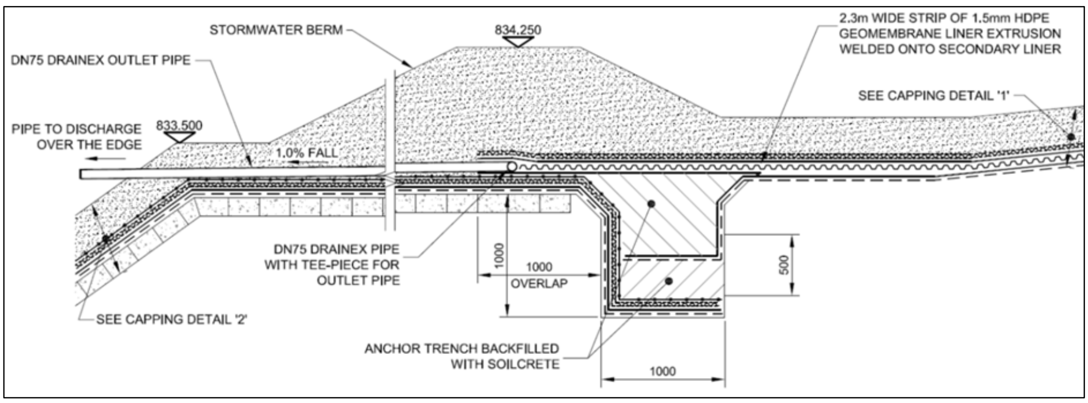

Figure 5. Cross section through leakage drainage collection and outlet pipe around perimeter.

5.2 *Steep Side Wall Capping Design*

Given the steep 1(V):1.5(H) gradient of the Capped Facility's side slopes, the most challenging aspect of the design was to develop a feasible capping system which succeeded in isolating the waste body from the receiving environment, while ensuring long term structural stability of the system. The steep gradient, however, also promotes rapid runoff so that the required composite barrier design was relaxed for this portion of the capping system.

The capping system design is presented in Figure 6 and consists of the following layers (from top downwards):

– 300 mm thick topsoil with grass and biodegradable erosion blanket;
– Geogrid reinforced geomat ;
– Geocomposite drainage layer;
– 1.5 mm thick HDPE geomembrane liner (single textured, facing down);
– Non-woven, needle punched geotextile and seams overlapped and heat-bonded, placed onto the existing concrete surface; and
– Existing concrete surface to be repaired locally to remove any sharp protrusions and to fill any voids.

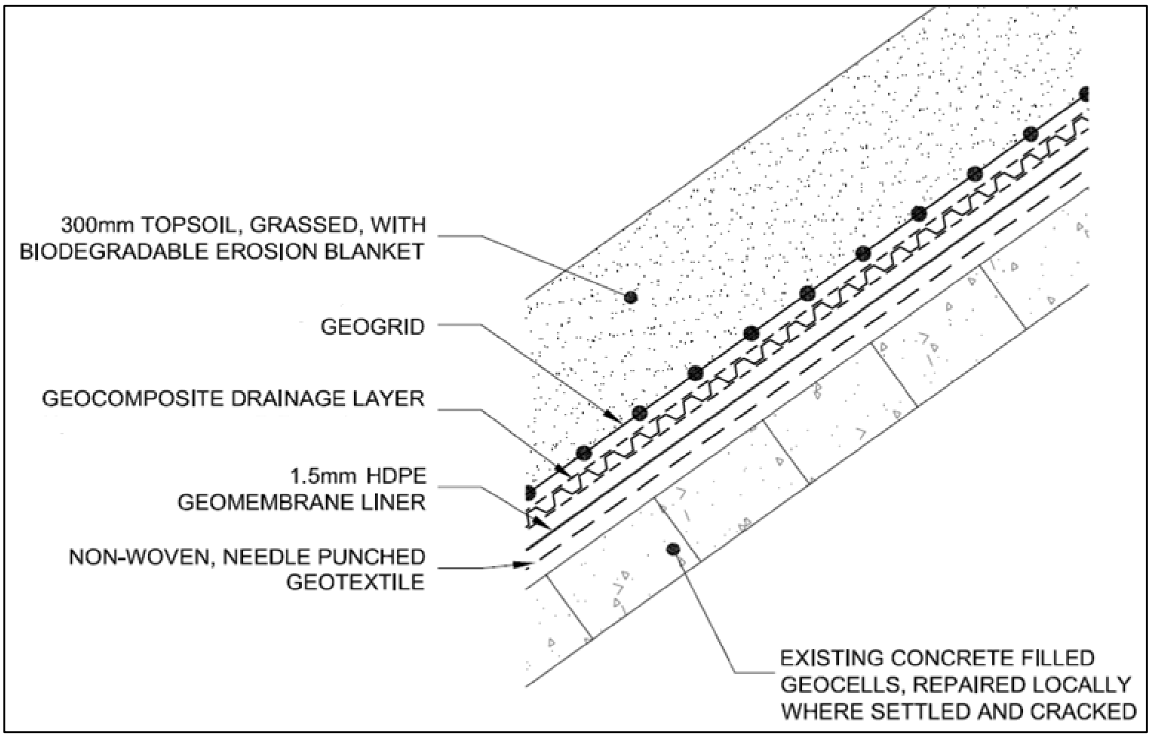

Figure 6. Capping system over steep side slopes.

To provide tensile strength to support the outer cover soil layer above the capping system, geogrid reinforcement was included in the design. Prior to the installation of any geosynthetics, however, the design requires that the existing concrete filled geocell surface is carefully inspected and locally repaired with hand-placed concrete where damage and sharp protrusions are present. Thereafter a thick nonwoven, needle punched geotextile is installed longitudinally down the slopes with the top secured in the anchor trench around the top surface perimeter. The side seams of the geotextile require appropriate overlapping and heat-bonding along the entire length. The geotextile acts as a protection layer for the geomembrane as well as a leakage drainage layer for any leakage that may occur through the geomembrane liner.

A 1.5 mm single textured HDPE geomembrane liner is then installed over the geotextile with all seams fully welded, and secured in the top anchor trench. This geomembrane is textured facing down over the geotextile in order to create friction and thereby spread the tensile forces resulting from the weight of the geomembrane itself. The side facing up is smooth so as to ensure minimal additional friction and tensile forces as a result of the cover material to be placed above the geomembrane. A geocomposite drainage layer was included over the geomembrane to account for seepage through the cover soil layer and prevent a buildup of pore water pressure, which may otherwise cause erosion. This layer daylights at the toe of the slope, directing any seepage into the upgraded surface water perimeter toe-drain, as seen in Figure 7.

In order to carry the load of the 300 mm thick cover soil layer over the geomembrane, a specialised geogrid is placed directly over the geomembrane and anchored in the anchor trench around the top of the facility. The geogrid is bonded to a textured geomat which provides adequate friction forces to hold the cover soil on the slope. The surface of the soil cover is covered with a biodegradable erosion blanket and vegetated by means of hydroseeding.

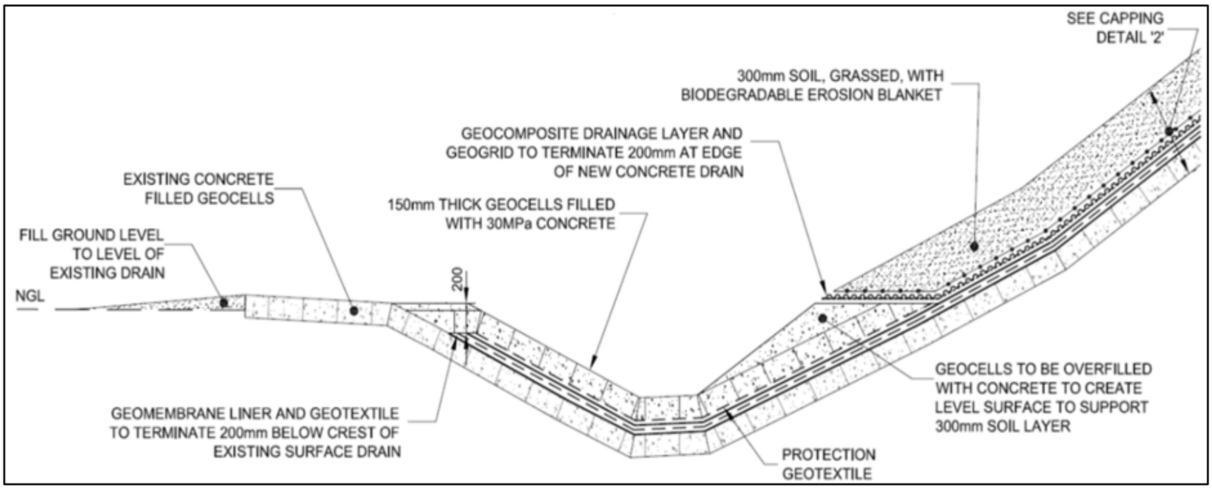

Figure 7. Integration of side wall capping system into surface water perimeter drain.

5.3 *Veneer Stability Analysis*

Due to the steep gradient of the side slopes with soil cover layer, a detailed analysis of the veneer stability of the capping system was conducted during the design process. The veneer stability analysis followed the method described in “Designing with Geosynthetics” (Koerner, 2012) to determine the factor of safety (FoS) for two scenarios as follows:

- FoS without geogrid reinforcement ($FoS_{unreinf}$) – interface between soil cover and geomembrane or geotextile; and
- FoS with geogrid reinforcement (FoS_{reinf}) – interface between underlying geosynthetic (geocomposite drain) and cover reinforcement (geogrid).

The use of a geogrid reinforced geomat was selected in this design for its ability to provide the necessary stability within the capping system, resulting in an appropriate factor of safety described above. The tensile strength necessary for veneer stability is provided through the geogrid, whilst the geomat component provides a mechanical interlock to retain the soil with the geogrid. The geomat is made up of a three-dimensional matrix of heat-bonded synthetic fibres, which are extruded onto a polymeric geogrid reinforcement. An example of this geosynthetic product is provided in Figure 8.

The full veneer stability analysis takes account of various factors including the properties of the cover soil, slope angle, geogrid properties, and other factors. Soil properties were obtained from geotechnical testing on actual samples taken from the material to be used in the cap, while material properties of the geosynthetic materials were obtained from the manufacturer. The result of this veneer stability analysis was as follows:

- $FoS_{unreinf}$ = 0.49; and
- FoS_{reinf} = 1.62.

From the above determined values, it was evident that reinforcement was necessary in the capping design, as provided by the geogrid. With reinforcing included, the veneer slope stability analysis indicates an acceptable FoS of 1.62.

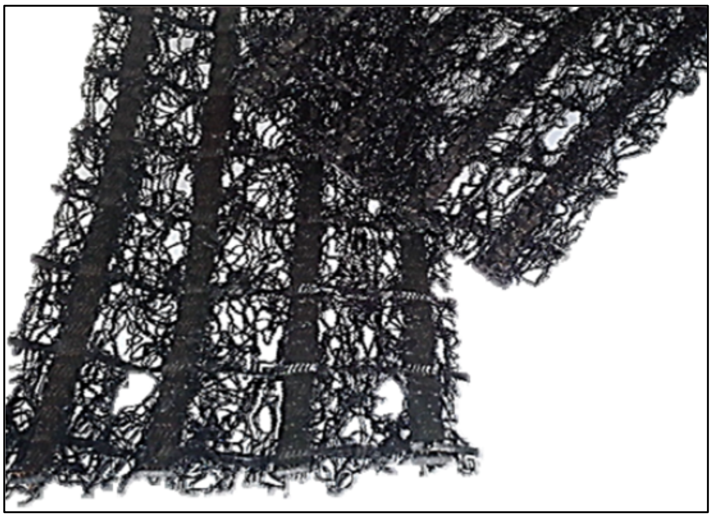

Figure 8. Geogrid reinforced geomat. (Maccaferri)

6 CONCLUSION

This paper has presented a feasible and effective solution to the capping of steep side slopes, albeit in a site-specific scenario. The impermeability of the cap was provided by the geomembrane liner, while protection was provided in the form of geotextiles and a grassed cover soil layer. The most challenging aspect of the capping design in this steep side wall scenario, namely the veneer stability of the cap, was provided by the geogrid reinforced geomat.

It is submitted that variations of the design presented herein, with alternative geosynthetic products, could provide similar results. Varying site conditions are also likely to necessitate the customisation of this design. Basic factors such as the cover soil material properties can significantly impact the veneer stability of such a system and potentially limit the design to much flatter gradients. Nonetheless, this design and the facts presented in this paper highlight the versatility and effectiveness of geosynthetic solutions to challenging capping scenarios.

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