Regulations and recommendations describing the use of geosynthetic barriers – A brief summary of regulated applications

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ABSTRACT: Over the past 40 years, the advantages in utilizing geosynthetic barriers versus traditional barrier materials have been well documented: greater project economy, extended service lives, enhanced environmental protection, greater site safety, etc. Achievements such as conserving water resources and enabling beneficial site reuse (e.g., remediation) have even given geosynthetic engineering a level of social importance. As such, the use of geosynthetic barriers has increasingly been required. This is especially true in modern waste management cell design, a barrier application that has been so successful it has influenced the design and specification of geosynthetics into mining, water and wastewater, and industrial applications. However, there are regions and applications in which the use of these barrier technologies should be more widely adopted. This paper highlights an overview of applications where geosynthetic barriers are used and where regulation or recommendations are available.

Keywords: Geosynthetic Barrier, regulations, requirements design landfill mining, hydraulics roads

1 INTRODUCTION

Geosynthetic barriers are an established product group in the geo-environmental industry. They include factory-made polymeric geomembranes (e.g., HDPE), bituminous (bitumen attached to geotextile), and geosynthetic clay liners (with clay/bentonite core). These geosynthetic materials are accepted as barrier solutions for landfill caps and base liners, under roadways and railways, and with various containment structures such as dams, canals, ponds, rivers, and lakes. They are also used for waterproofing of buildings and similar structures.

Advantages of geosynthetic barrier systems vs. traditional designs include:

- More economical to produce, transport, and install
- Enable predictability designs
- Quicker, simpler installation
- Reduced excavation required (e.g., less fill required, less land disturbed)
- Clear, established quality controls from production through installation
- More homogeneous than soil and aggregates
- Less environmentally sensitive and lower environmental impact
- Improved performance and durability

The use of geosynthetic barriers continues to grow internationally, but more regulatory support is needed.

2 BRIEF HISTORY OF POLYMERIC BARRIER SYSTEMS

Polymeric geomembranes (smooth or textured surface) are essentially impermeable and are used as fluid barriers in geotechnical engineering. Textured surfaces provide an enhancement of frictional characteristics, which allows designs on steeper slopes or where shear stress occurs (e.g., with a geosynthetic-soil or geosynthetic-geosynthetic interface).

Geomembrane liner materials belong to the group of geosynthetic polymeric barriers and the terminology of these types of products are currently under discussions in ASTM as follows:

- Polymeric geosynthetic barrier (GBR-P): Factory-assembled structure of geosynthetic materials in the form of a sheet in which the barrier function is fulfilled by polymers other than bitumen.
- Polymeric geomembrane: Factory-assembled geosynthetic barrier consisting of one single flat polymeric core of thickness greater or equal to 0.75mm (30 mils).

Not all countries are in agreement on that definition. In France and Germany, for example, the polymeric barrier is considered a geomembrane if the thickness is equal or greater than 1mm (40 mils).
Geosynthetic clay liners (GCLs), a second very successful barrier group, are made of a thin layer of typically sodium bentonite between two layers of geosynthetics; generally, these layers are nonwoven and woven geotextiles. GCLs can be used as a stand-alone barrier or in conjunction with a geomembrane.

Similar to geomembrane, the terminology is also being reviewed at ASTM with the following definitions:

- Geosynthetic clay barriers (GBR-C): Factory-assembled structure of geosynthetic materials in the form of a sheet in which the barrier function is fulfilled by clay. [Current ASTM terminology discussed definition – similar to ISO 10318]
- Geosynthetic clay liners (GCL): Factory-assembled geosynthetic barrier consisting of clay supported by geotextiles that are held together by needling, stitching, or a chemical adhesive. [Current ASTM terminology discussed definition]
- Multi component Clay geosynthetic barrier (MGCL): A Clay or Geosynthetic Clay Liner (GCL) with an attached bituminous, polymeric or metallic barrier decreasing the hydraulic conductivity or protecting the clay core, or both. [Current ASTM terminology discussed definition]

2.1 *Growth from waste management*

Synthetic containment designs began in the 1950s, often with canal systems and water conveyance, and have expanded steadily since with new manufacturing technology, better polymeric formulations and additive packages, and stronger engineering education. Geosynthetic barriers have been used in lieu of traditional concrete, asphalt, and compacted clay-only barriers, which have not been as effective at preventing fluid migration into subsurface soils and groundwater.

A major spur to the utilization of geosynthetics occurred in the early 1980s when the United States, on a federal level, began to regulate and require the use of geosynthetic barriers to meet minimum containment criteria for landfills. The legacy of this regulatory move is that today the American Society of Civil Engineers (ASCE) lists waste management as the best infrastructure sector in the United States (ASCE 2013). This is likely to be true in many countries, where modern landfill designs and geosynthetic technologies are used. However, still too many countries are missing guidelines for the use of geosynthetic barriers in landfills and other applications.

Manufacturers, over the years, have contributed new products, research, testing options, and design support to facilitate even more successful and economical barrier solutions while meeting and exceeding environmental guidelines.

The stringent requirements developed between government and industry have created extremely low total seepage as measured through monitored geomembrane installations. This is especially true of geomembranes installed along with GCLs (GMA 2010).

3 BARRIER APPLICATIONS

3.1 *Waste – Base liners*

Landfills use geomembranes and GCLs as bottom liners, for leachate ponds (see section 3.3 and 3.8), in cut-off walls, and for closure and cover (see section 3.2). While most regulations require a geomembrane or a clay liner as single liner in construction waste landfills, GCLs – as replacement of the compacted clay liner - are often used with the geomembrane as composite lining system to form high-effective barrier system in hazardous and most municipal solid waste (MSW) landfills. MSW landfills typically require a single composite liner comprised of a leachate collection and removal system and a geomembrane overlying either a GCL or compacted clay soil. Hazardous waste landfills generally require double-liner systems (two geomembranes), often incorporating both GCLs and compacted clay (GMA 2010).

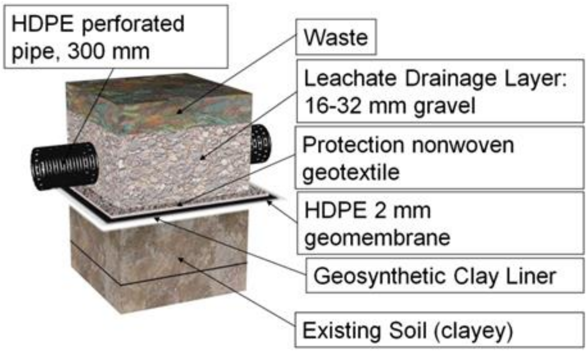

Figure 1. Typical cross section of a composite lining system in a landfill base with geosynthetics.

In the US, landfills are first regulated by the federal-level Environmental Protection Agency (EPA) through a rulemaking process. MSW, hazardous waste, and certain other wastes are regulated under RCRA (Resource Conservation and Recovery Act). The EPA utilizes the RCRA state authorization process to delegate primary responsibilities to state and US territory environmental entities (EPA, 2013b).

This process ensures national consistency and minimum standards while providing some state and territory flexibility. State-level must be at least as stringent as the federal requirements. More stringent rules may be adopted by states. This is very similar to how other countries approach waste management. In Germany, the national law DepV regulates landfilling; landfill sealing system requirements are controlled by the “Umweltbundesamt”, which is the counterpart to the US EPA. The DepV grants authority to the Federal Institute for Materials Research and Testing (BAM) to describe the requirements and certify geomembranes, geogrids, geosynthetic drainage mats, and nonwoven protection and filtration geotextiles for use in landfills. GCLs and other clay materials are dealt with in the LAGA, which is the Federal and State Working Society for Waste. Any geosynthetic installed in a German landfill has to have the approval or certification from these organizations.

In the US, the RCRA Subtitle C generally requires hazardous waste landfills to have a double-liner system with a leakage detection system (LDS) between the two independent liners and a leachate collection and removal system (LCRS) above the primary liner. This is a different approach to some other countries. In the case of Germany, double-lined landfills are not required in the DepV. The double-liner system concept was first presented 1973 by J.P. Giroud (2014) and used by the same author for containment of the Pont-de-Claix reservoir in southeastern France in 1974 (Badu-Tweneboah et al., 2013). The purpose of the LDS is to allow monitoring of the primary liner, to identify whether, and to what extent, leakage is occurring through the primary liner. The LDS also provides a mechanism for removing liquids that enter this system. The performance of double-liner systems for waste landfills constructed in North America with respect to their field effectiveness to contain leachate have often been evaluated and reported to be satisfactory (fig. 2), such as by Bonaparte et al. (1999); especially in conjunction with a GCL in the primary liner.

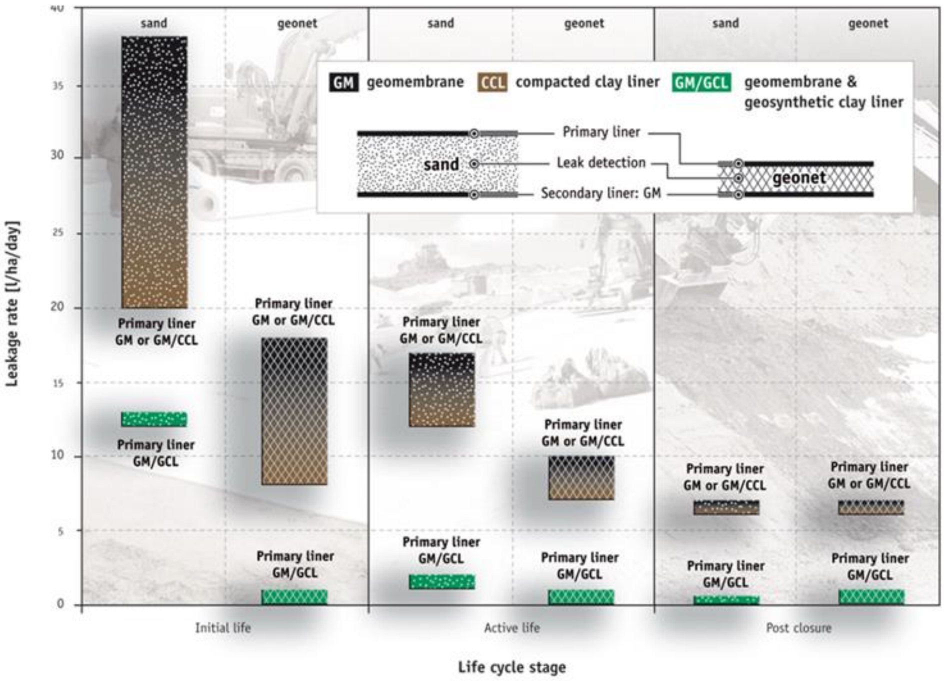

Figure 2. Performance of double-liner systems for waste landfills constructed in North America with respect to their field effectiveness to contain leachate.

3.2 *Waste – Caps and closures*

Geomembranes and GCLs are used for landfill caps to prevent fluid migration into the landfill, thereby reducing or eliminating post-closure generation of leachate and the associated treatment costs. The cap is also designed to trap and properly vent the gases generated during decomposition of organic wastes. Similarly, the closure system can prevent the seep of any fluids from the refuse body to the landfill surface. Often GCLs are added beneath the geomembrane to form a composite lining system. Geomembrane and GCL closure systems can also be designed to facilitate future vertical expansion of the landfill, thereby enlarging the landfill capacity. By fully encapsulating the refuse, the completed cap enables the safe and efficient restoration, re-vegetation, and possible reuse of the land. Other countries need to follow this road and regulate the disposal of coal ashes and slurries in approved, lined facilities.

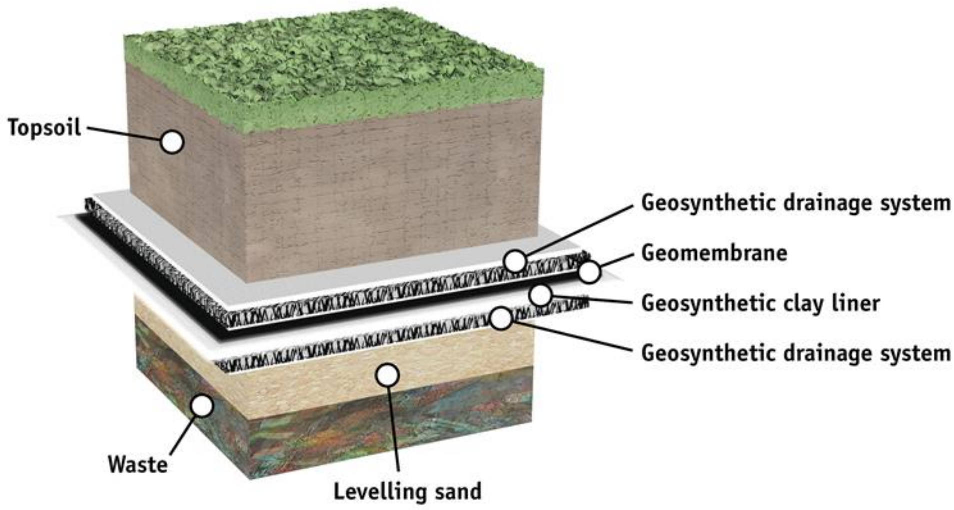

Fig. 4: Typical cross section of a landfill closure system with geosynthetics

3.3 *Coal ash applications*

Coal is an important source of power throughout the entire world. Approximately 7 million metric tons of coal are mined and burned each year around the globe. The result of the combustion of these huge volumes of coal is the generation of power, electricity and the creation of coal ash – roughly 20 % of the weight of the coal. This ash is often quite useful and is perhaps the largest (in volume) recycling success story in the world. Useful applications for coal ash include concrete, fiberboard and a host of other construction and infrastructure applications. In some parts of the world, nearly 100% of the coal ash is recycled. However approximately half of the coal ash generated in the world is not recycled and is disposed of. How coal ash is disposed of varies widely. In some parts of the world, the coal ash is simply “dumped”, more developed nations may dispose of coal ash in large de-watering ponds, store the coal ash using very large levees and use the materials as structural fill to modify the shape of the earth; creating flat areas for airports for example. The proper disposal of coal ash is important to the health of the planet and to human health. Leachate (water that has passed through coal ash) from coal ash is high in heavy metals, such as lead, arsenic and others, and serves as a global contaminate to groundwater and potable water resources.

In recent years there have been several failures of coal ash storage facilities in the United States and other locations. A December 2008 failure at the power facility in Kingston, Tennessee, USA spilled 4,200,000 m^3 of coal fly ash slurry into the Emory River, covering up to 300 acres (1.2 km^2) of the surrounding land, damaging homes and flowing up and down stream in nearby waterways. It was the largest fly ash release in United States history and over 1.4 billion US dollars have been spent on remediation. This, along with the October 2011 failure in Oak Creek, Wisconsin and the February, 2014 coal ash spill into the Dan River near Eden North Carolina brought attention to the above ground long term disposal of coal ash.

In addition, over 50 documented cases of groundwater contamination at or nearby coal ash storage facilities contributed to the US EPA‘s issuance of new regulations for the storage of coal ash which require the use of geosynthetic materials and proper geotechnical engineering of coal ash disposal sites. Other “levee failures” such as Mt Polley – Canada, MAL Aluminum in Hungary and the Samarco Brazil failure are other tragic incidents and are only mentioned as an addition. The US EPA regulations for coal ash storage propose the most efficient and effective barrier system as a composite liner system using a primary geomembrane (GM) liner, in combination with a compacted clay liner (CCL), approx. 500mm thick or a needle-punched Geosynthetic Clay Liner (GCL), although other variations exist. This is a direct result of that system(s) being compliant with the United States Environmental Protection Agency (US EPA) Resources Conservation and Recovery Act (RCRA) Subtitle "D" regulations which have demonstrated excellent historical performance as barriers.

3.4 *Surface impoundments*

Numerous national regulatory bodies have passed wide-reaching clean water legislation. Many of these regulations require the use of geomembrane liner systems in treatment lagoons at publicly operated wastewater treatment plants. In many other situations, geosynthetic barriers are indirectly required in order to meet more stringent performance criteria.

Geosynthetic barriers are also being used in potable water reservoirs (e.g., liners and floating covers). Here, these materials and systems have helped conserve water annually by minimizing water seepage. Also, storm water retention and detention management increasingly requires smart lining solutions and includes geomembranes, geosynthetic clay liners and multi-component lining systems.

Geosynthetic products can also be used for practical or decorative pond liners at golf courses, amusement parks, and resorts, as well as in agriculture and aquaculture to create healthier, more efficient, and cost-effective systems. Some of these applications are also covered in regulations or recommendations.

3.5 *Mining applications*

Advanced extraction processes involving chemical solutions and large heap leach pads help to economically recover precious metals from low-grade ores. Geomembranes and GCLs under the large leach pads prevent the loss of valuable metal-laden chemical solutions while protecting soils and groundwater. Geosynthetic barriers are also used to recapture and recycle harmful chemicals on site and in secondary containment applications. Geosynthetics can aide in channeling surface water run-off and in preventing rainwater intrusion into heap leach pads, thus minimizing solution dilution.

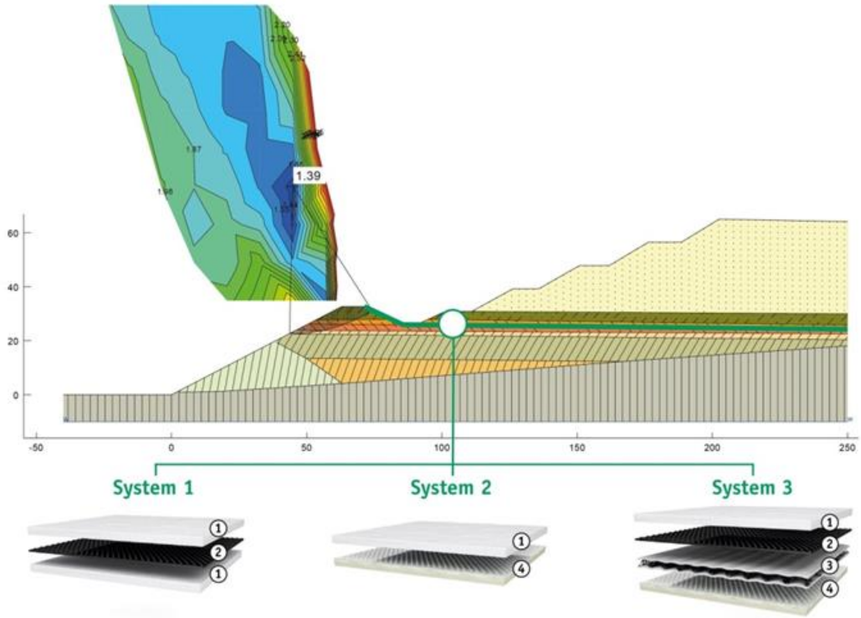

Fig. 5: Typical cross section of a heap leach pad in a mining application with geosynthetics with three possible sealing systems (1 nonwoven geotextile, 2 geomembrane, 3 geosynthetic drainage mat, 4 geosynthetic clay liner)

In general, few regulations govern mining usage of geosynthetic barriers. Basic environmental laws apply, country by; but the mining industry is unique in that it increasingly adopts geosynthetic barriers primarily for economic advantages. Up to 40% of the world's annual production of geomembranes are now used in mining (Christie 2013). This growth has been driven by heap leaching, which was only a small percentage of gold and copper production in 1980 but today accounts for upwards of 40% of all gold and copper production methods (Smith 2013). Uranium and rare earths are another major growth application globally in which geosynthetic barriers are enabling efficient heap leaching.

3.6 *Environmental protection in infrastructure applications - RISTWAG*

Groundwater protection is generally required where a road enters a groundwater sensitive area, to avoid damage from winter maintenance with deicing salt, everyday pollution arising from motor vehicles, and to protect the area from accidents with the possible release of polluting substances (chemical/petroleum tankers/transporters). The German Guideline of the RiStWag (Guidelines for Construction Projects in Waterways of Protected Areas) (1982; 2002; 2015) from the Research Society for Road and Traffic was one of the earlier guidelines on this topic. The guideline describes, among other things, geosynthetic sealing systems for environmental protection.

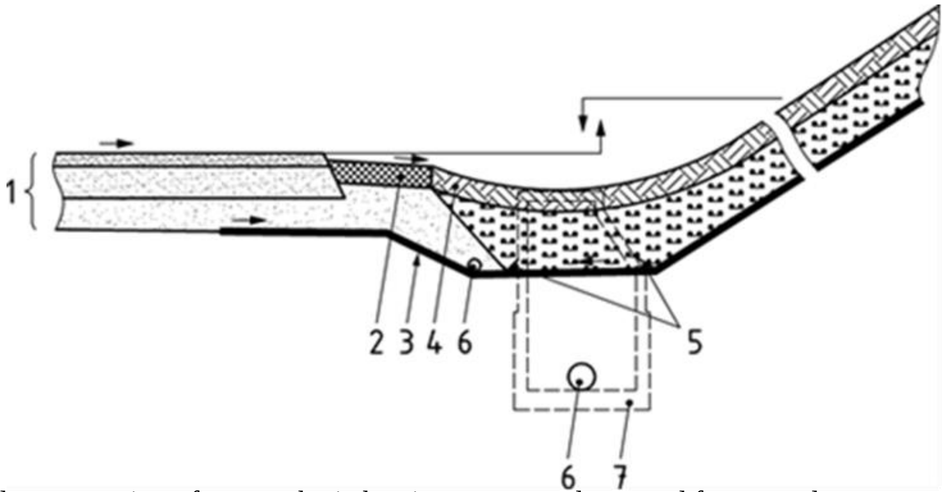

Fig. 6: Typical cross section of geosynthetic barrier system under a road for groundwater protection (1 pavement, 2 side embankment, 3 geosynthetic barrier (GBR), 4 cover soil, 5 sealing connection, 6 collection pipe, 7 manhole)

3.7 *Encapsulation of contaminated soils*

Road noise and view-blocking barriers along roads, motorways and railway lines are being built with a mineral waste core. This may include slag, ash, contaminated soils from remediated sites, and residue from construction waste recycling or industrial processing. These wastes must meet certain environmental-chemical requirements and must be provided with a surface sealing for groundwater protection.

In Germany, as in other European countries (e.g., the Netherlands), protecting the environment during the recycling of waste is carried out using three barriers, similar to modern landfill practices:

- Hydraulic permeability of the subsoil, depth to groundwater table, groundwater-protecting cover layers
- Limitation of pollutant load through assigned threshold values
- Technical protection measures using water impermeable cover and sealing layers

Suitable sealing materials for these purposes include GCLs and geomembranes.

In the Netherlands, this construction is directed by the “Bouwstoffen Besluit” (CUR 1999). In Germany, the guidance comes from the FGSV’s MTSE guideline (MTSE 2009). These documents provide technical information on the possible design of such protection measures and sealing components in order to meet the high stability requirements (> 100 years).

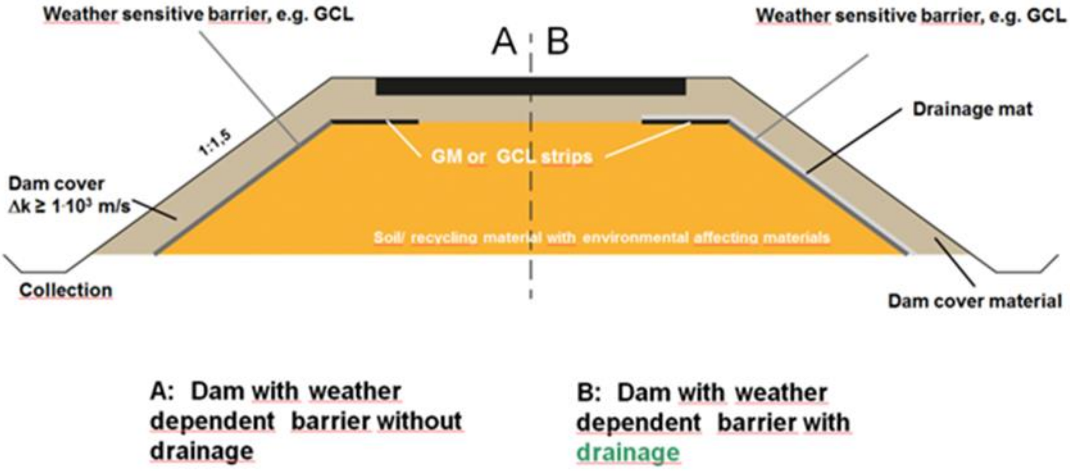

Fig. 7: Typical cross section of geosynthetic barrier system for the encapsulation of contaminated soils in road constructions

3.8 *Water conveyance in canals*

Government agencies such as the United States Bureau of Reclamation (BuRec) indicate that seepage from unlined irrigation canals and waterways may be substantial and costly; and that geosynthetic barriers offer economically flexible and highly effective performance enhancement for canals (Swihart and Hanes, 2002). They are effective alternatives to concrete, asphalt or compacted clay soils.

Stark and Hynes (2009) summarized numerous geosynthetic barrier installations in canal systems, including single geomembranes (various polymers), exposed and buried installations, and composite systems, such as geomembrane with geotextile protection or concrete cover. This evaluation includes cost information and inspection/review information.

No matter the construction, the consistent revelation is that geosynthetic liners and lining systems have outperformed traditional lining methods in longevity and project economics in canal systems.

In Germany, all important technical information on waterway lining systems has been collated in the new guideline, “Recommendations for the use of lining systems on beds and banks of waterways.” The guideline, taking into account local boundary conditions, provides liner system selection information to be used by agencies, such as the Wasser-und Schifffahrtsverwaltung (the Federal German Waterways and Shipping Administration, referred to below by the German abbreviation “WSV”). The focus is primarily on the underwater installation of lining systems on waterway slopes and beds. The guideline describes geosynthetic lining systems, which additionally need to be covered with rock armor as specified in the MAR code of practice.

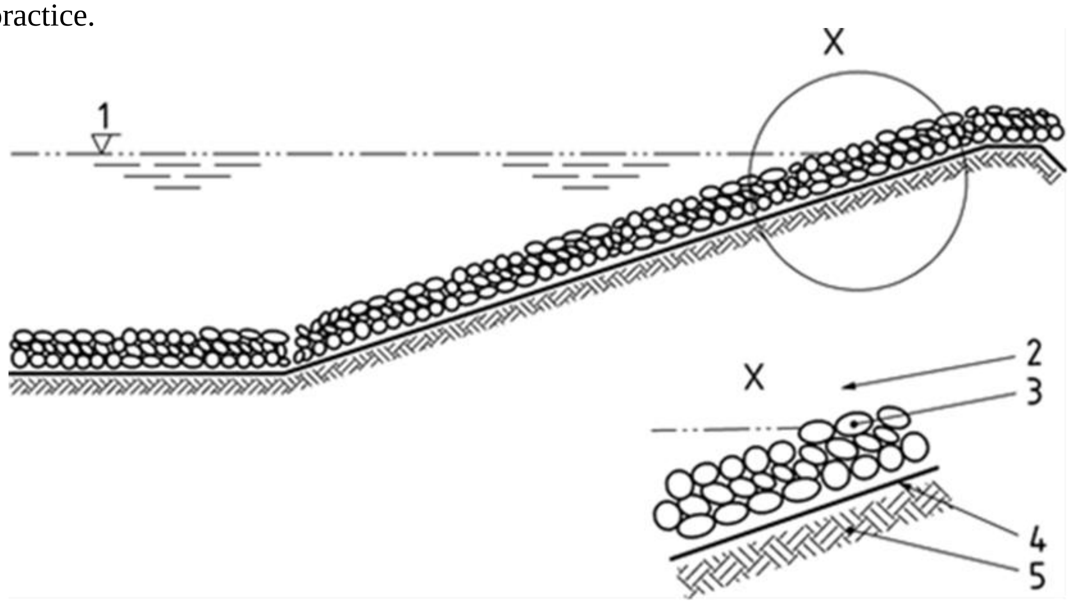

Fig. 8: Typical cross section of geosynthetic barrier system as a canal lining system (1 top water level, 2 upstream face, 3 revetment, 4 geosynthetic barrier, 5 dam body)

4 DESIGNING WITH GEOSYNTHETIC BARRIERS

Currently ISO/TC 221/SC /WG 6 is developing an technical report ISO/TR 18228-9 "Design using geosynthetics — Part 9: Barriers". The scope is: Design using geosynthetic barriers (GBRs) takes into account the nature of the material in contact with the GBR, both underneath (the substrate), alongside and on top (the contained substances). As the primary function of a GBR is to retain or exclude fluids, primary issues in design relate to its ability to perform this function. Often, but not always, GBR materials are incorporated into structures with an extensive life expectancy and therefore the material's durability (its ability to continue to perform its primary function over time) is critical.

This international standard contains recommendations and guidance for the design of geosynthetic barriers in geotechnical applications. The standard provides design guidance over various applications, design lives, material types, parameters and site specific conditions. Professional judgement is needed in all designs. Be aware that national regulations might apply. This document is intended to assist in the process, by identifying parameters which are relevant.

Balancing the combination of often conflicting performance criteria and different GBR materials to the proposed installation, is always a complex matter. This inevitably comes down to professional judgement. This document does not set out to and cannot solve this potential conflict, but seeks to assist the designer in identifying and clarifying the various components of the decision-making process by identifying existing standards for comparisons of individual parameters and giving some direction on prioritization in various applications as well as conflicting performance characteristics which may be encountered.

The document gives a lot of guides on what to consider in barrier applications. It covers installation aspects, weather conditions as well as raw material aspects of the barrier system. Table 1 gives a subjective rating for importance of various criteria of common GBR applications.

Table 1: Importance of various criteria of common GBR applications, such as Containment application, non-landfill (CA); Chemical containment, non-landfill (CC); Construction waterproofing (CW); Landfill base lining (LBL); Landfills caps (LC); Secondary containment (SC); Transport infrastructure applications (TIA); Tunnels (Tu); Water retaining structure (WRS-e), e.g. balancing ponds, dams, dykes and canals (usually empty); Water retaining structure (WRS-f), e.g. reservoirs, canals (usually full)

Characteristic Parameter		CA	CC	CW	LBL	LC	SC	TIA	TU	WRS-e	WRS-f
Chemical resistance		2	1	3	1	2	1	1	2	3	3
Physical properties											
Hydraulic resistance	permeability	1	1	1	1	1	1	1	1	1	1
Mechanical property	tensile, puncture, tear strength	1	1	2	1	1	2	1	1	1	1
	uni- and multi-axial elongation	2	2	3	3	2	2	2	3	2	2
Abrasion resistance		4	4	4	4	4	4	4	4	2	2
Durability		50 yrs	25 yrs	50 yrs	100 yrs	50 yrs	25 yrs	25 yrs	100 yrs	25 yrs	25 yrs
Installation		1	1	1	1	1	1	1	1	1	1

In the section "Principles of design" The GBR and its substrate form the construction which will has an expected design life and would normally be considered as a primary part of the process. It is important not to select low cost, low performance materials just because the structure only has a short life. If the potential risk from failure of the structure is high then this would override the financial aspects of the design process but can still impact the required lifespan of the components.

The whole process is overshadowed by an assessment of the risk versus value equation. Designers would normally consider the whole range of issues and feed into a pragmatic risk assessment process such that the ultimate design, its components and its installation provide an appropriate completed system. Including sufficient factors of safety commensurate with the consequences of failure, be they limited or catastrophic.

5 CONCLUSION

There is every reason to believe that geosynthetics will continue to be adopted into regulations around the world. As Koerner notes (2014), no other field of engineered materials has developed as rapidly or gained such wide-spread acceptance as geosynthetics. This has much to do with the innovation and quality control measures in manufacturing and care of handling in the field. It also has much to do with geosynthetics being used in two primary situations: to perform better and/or more economically than traditional geotechnical designs. With a large record of data in support of cost and performance measures, and with secondary benefits such as decreased project carbon footprints with geosynthetics, the field's growth is assured.

Regulatory bodies will continue to incorporate them. For barrier applications, this means geomembranes and GCLs.

These geosynthetics offer a wide range of physical, mechanical and chemical resistance properties. Geomembranes can be compounded for greater resistance to ultraviolet light exposure, ozone and microorganisms in the soil, while GCLs can be produced with various geotextiles for enhanced frictional properties. Different combinations of these properties exist in various geomembranes as well as GCL materials to address a wide spectrum of geotechnical applications and designs. Several methods are used to join or seam large panels of geomembranes and GCLs, in both factory controlled and field environments. Each material has highly developed quality control techniques and unique characteristics that govern their manufacture and installation.

As advanced products and manufacturing and installation techniques evolve, project economy and performance will continue to improve, both with and in wait of regulatory recognition.

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